WELLS AND BORE-HOLES FOR WATER SUPPLY

THE CONSTRUCTION
OF
WELLS AND BORE-HOLES
FOR
WATER SUPPLY
AND
THE ELEMENTS OF THE ANALYSIS AND PURIFICATION OF WATER

BY

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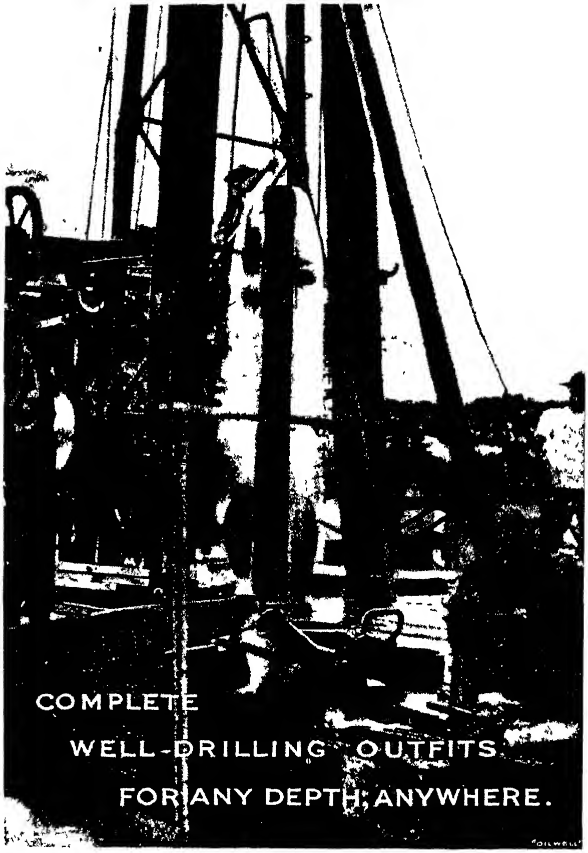
LONDON
CROSBY LOCKWOOD AND SON
7, STATIONERS' HALL COURT, LUDGATE HILL
1925



BORING & DEEP WELL PUMPING MACHINERY

OIL WELL SUPPLY CO.

Dashwood House,

LONDON, E.C. 2.

PREFACE

ONE of the principal reasons why a comparatively large number of wells in the past have finally proved to be failures is that the limitations of boring for water are not always sufficiently appreciated. Therefore the author ventures to take this opportunity of pointing out that it is only under certain circumstances that borings can provide a suitable supply, and that it is essential to take every precaution to ensure that the demand for water will be satisfied by that available before any work is started.

In many country places in Great Britain the water supply is still deplorably poor both in quantity and quality, and in such areas attention is particularly directed to the possible value of boring; especially for rural districts and isolated houses, where the expense of unproductive lengths of pipe cannot be considered, borings may sometimes provide a satisfactory and economical solution of the problem of water supply. Again, a boring will often yield a supply of moderately pure water suitable for manufacturing purposes at a fraction of the cost of a supply from a water company, particularly in such districts as the London Basin, where conditions are favourable for artesian supplies and where, consequently, the expense of pumping can be avoided or reduced to a very small annual charge. It is only in exceptional cases that borings will yield sufficient water to provide an adequate supply for a large town.

In presenting this book the author wishes to acknowledge his indebtedness to the work of Mr. J. G. Swindell and Mr G. R. Burnell, joint authors of *The Rudimentary Treatise on Wells and Well-Sinking*, from which many passages have been abstracted. It was originally intended to prepare a revised edition of the above work, but the alterations necessary to a work some fifty years old were found to be so considerable that the alternative of preparing a new book on similar lines was necessarily adopted

In preparing this book, especially where new matter has

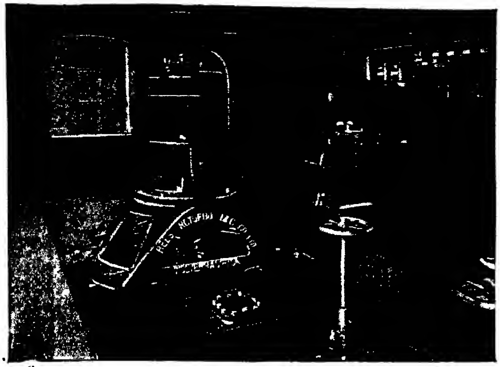
been substituted for those parts of the old editions which were rendered obsolete as a result of fifty years' progress, every effort has been made to retain the object of the earlier editions, viz. "to condense in a general practical manner many subjects connected with well-work". In certain cases the original well work has not been materially altered, particularly parts of Chapters I and VII, which contain many points of historical interest, and also certain sections of Chapters II and IV in cases where experience and research have not added appreciably to modern methods and knowledge.

The scope of such a book as this is necessarily limited, but an attempt has been made to include essential matter without entering into unnecessary detail and to place general principles before the reader rather than confuse him with condensed theoretical considerations.

Boring for water is useless if the water obtained is unsuitable or insufficient to fulfil the purpose for which it was intended, so that the method of construction of a well or boring is only a part of the knowledge required and the *modus operandi* of this is now widely understood. In addition, it is necessary to be able to determine with considerable accuracy (1) the volume and properties of the water likely to be obtained from the boring, (2) its suitability for a potable or manufacturing supply, (3) the effect of the boring on adjacent wells, and (4) the nature and probable causes of any pollution, together with the best means of counteracting it. It is for this reason that considerable space has been devoted to the yield of wells and to the properties, analysis, and purification of water.

The author would express his gratitude to the Institution of Civil Engineers for permission to include abstracts from the *Proceedings*, to Messrs. Isler and Co., Ltd., for supplying details of boring plant and the boring chart reproduced at the end of Chapter I; also to Messrs. Sulzer Bros. for information regarding borehole centrifugal pumps and to Messrs. Boulton and Paul, Ltd., for permission to include diagrams of the Boulton Water Elevator.

J E D.



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CHAPTER IX

WELLS AND BORE-HOLES.

CHAPTER I.

PRELIMINARY OBSERVATIONS.

THE practice of obtaining water from wells is of great antiquity. In the Hebrew Scriptures, the earliest record of the human race, many instances are cited of the importance attached to them in the burning plains of Syria, where, from the accounts handed down to us, they appear to have been mere excavations in the sides of rocks and hills in which springs of water were plentiful, the water rising so near the surface as to be reached by a bucket attached to a short rope. In Greece, this plan for raising water was common, and in many cases the orifice of the well was finished by a cylindrical curb of marble, which was sometimes beautifully carved.

The method of boring for water is of an antiquity very nearly as great, although the precise epoch of its introduction is unknown. In Syria and Egypt, it is reported that many fountains fed by waters obtained in this manner exist, and that the greater number of the oases of the Libyan chain owe their existence to similar works. M. Degousée mentions that he delivered to the Pacha of Egypt a set of tools for the purpose of reopening some of these wells, whose original construction probably dated some 4,000 years back; and when the works were completed, it was found that the wells were lined with brick or wood. The details of the method used in sinking these wells are not known.

In China, however, the system of boring is ascertained to have been long practised, and a French missionary, the Abbé Imbert, has given an account of the methods there adopted, which was (as M. Degousée rather dryly remarked) more characterized by credulity than by discernment. It is quoted in Degousée's *Guide du Sondeur, ou Traité Théorique et Pratique des Sondages*, as follows:—

"There exist in the province of Ou-Tong-Kiao many thousand wells, in a space of ten leagues long by five

broad. Each well costs about one thousand and some hundred taels (the taël is worth 6*s.* 3*d.*). These wells are from 1,500 to 1,800 feet deep, and of a diameter of from 5 to 6 inches.

"To bore them, they commence by placing in the earth a wooden tube of 3 to 4 inches diameter, surmounted by a stone edge pierced by an orifice of 5 to 6 inches. Then a trepan, weighing three or four hundred pounds, is allowed to play. A man mounted upon a scaffold depresses a lever which raises the trepan 2 feet high, and lets it fall by its own weight; the trepan is attached to the lever by a cord of ratan, to which a strip of wood is fixed; a man seated near the cord seizes this strip at each elevation of the lever, and gives it a half-turn, so that the trepan in falling may take a different direction. The workmen are changed every six hours, and the work goes on night and day. They are sometimes three years in boring these wells to the depth necessary to reach the springs they are intended to attain."

Almost all these wells give off considerable quantities of inflammable gas; there are some which yield, in fact, nothing else, and which are called "fire wells". It appears that the Chinese employ this gas as a combustible; doubtless it is nothing more than carburetted hydrogen, such as proceeds from coal mines in combustion. If M. Imbert may be believed, some of these wells are not less than 3,000 feet in depth.

In modern Europe the art of well-making was long confined to the simple operation of sinking circular shafts, until land-springs were met with; at least in the greater number of states. In the province of the Artois, however, the use of the boring-tool appears to have been generally known and practised from very early periods. The most ancient well in France, whose date can be authenticated, is one at Lillers, in the Artois, supposed to have been executed in 1126; and in that province the facilities for this description of work are such that a well is to be met with before the door of almost every peasant. In the north of Italy, at the very commencement of modern history, the arms of the town of Modena were two well-borers' augers; and a professor of medicine of that town published in 1691 a Treatise on Physics, in which many interesting notes are to

be found upon the nature of different strata and water-courses, upon overflowing fountains, upon the manner of boring for these, and upon the excellence of the water they contain. Dominique Cassini, about the middle of the seventeenth century, endeavoured to introduce the system of boring more generally; and Belidor, in his work *La Science de l'Ingénieur*, published in 1729, mentions the remarkable results which are often to be observed in these wells. He adds, evidently perceiving instinctively, so to speak, the theoretical conditions necessary to secure success in these operations: "It were to be desired that many similar wells to those obtained by boring were formed in all kinds of places; but this does not appear probable, because certain circumstances in the disposition of the earth are necessary, which are not always to be met with."

In our own country, the first notice we find recorded of the application of boring is in the *Parentalia*, in which Sir C. Wren is said to have adopted this precaution in order to ascertain the solidity of the foundation of St. Paul's in parts where the original surface of the ground had been disturbed. Subsequently, towards the latter end of the eighteenth century, many wells were formed by this means, especially in the Wolds near Louth, and in the London basin near Tottenham; and the real principles regulating the flow of water in these wells were ascertained to a sufficient extent at least to allow of their execution being attempted with such probability of success as to justify their being commenced.

The execution of the artesian well at Grenelle, near Paris, tended more than any other circumstance to direct public attention to this mode of obtaining water, not only on account of the remarkable success which crowned the efforts of the self-educated engineer, M. Mulot, in spite of all the difficulties and opposition he encountered in the long and anxious execution of the works, but also on account of the highly interesting discussions and the elaborate investigations to which it gave rise. MM. Arago and Walferdin followed the progress of the works in a spirit of enlightened philosophical inquiry which led to the solution of many highly interesting laws of nature hitherto involved in mystery; and at the same time their confident

predictions of the eventual success of the operation served to encourage M. Mulot, when too many others were disposed to throw doubt and ridicule on his efforts. The very remarkable confirmation of the deductions based on these investigations afforded also a remarkable illustration of the correctness of the accepted theory of the geological structure of the globe. But, singularly enough, the lessons afforded by this remarkable work were not productive of all the scientific results that might have been expected. Because water had been in this instance obtained in a position where there appeared no natural supply, it was too frequently concluded that in all such cases the same results would be obtained, and that quantities of water were pent up in the ground, which only required to be tapped to allow of its rising to the surface. But there are considerations affecting the supply, and the overflow from the water-bearing stratum, which so far modify the question as to render long and patient investigation necessary before such expensive borings, as these deep wells usually prove to be, should be commenced. Many disappointments were thus incurred in the search for what after all could not reasonably have been expected; nor would it be possible to cite a more striking illustration than to refer to a boring near to Southampton. This boring is discussed in more detail in Chapter III in considering the general theory of artesian wells.

The economy of the application of boring, instead of carrying down a shaft of considerable dimensions, must be evident. A remarkable instance is recorded of unnecessary labour, where, after an ordinary well had been sunk to a depth of 236 feet, a boring was commenced, and a copper pipe 5¼ inches diameter inserted. After boring 24 feet, the spring was tapped, and the water rose 243 feet in one hour and twenty minutes. The sand also blew into the well 90 feet, thus choking to a great extent the flow of water: by clearing some of this away, the water overflowed the surface at the rate of forty-six gallons per minute. This occurred in the year 1794. It is evident that, in this example, had the the advantage of boring been fully appreciated, and the geological situation of the place been accurately determined, much needless expense in well-sinking would have been saved.

In addition to its use in operations of well-work for water, boring is of service in a variety of ways; particularly for oil-drilling and for mining purposes, railway works, examination of ground for foundations, and piling. The reasonableness of its application is self-evident; a few pounds spent in boring may save hundreds which would be expended if the operation were neglected. It has, however, been proved repeatedly that for any operation of boring involving an examination of the strata penetrated, the method known as "core-boring" is the only reliable means of obtaining accurate results.

The application of boring to pile-driving has in some cases proved to be very successful. A prominent example is provided in the construction of the tunnel for vehicular traffic between New York and Jersey City under the Hudson River. A shaft is provided at each end of the tunnel, and the foundations of these shafts had to be carried on ferro-concrete piles driven through 30 feet of water and 220 feet of silt to a rock foundation under the bed of the river.

At an early date it was realized that these piles could not be driven vertically to so great a depth by power in the usual manner, and it was decided to resort to boring. 24-inch borings were therefore sunk and lined with steel pipes, into which the reinforcement and concrete were afterwards introduced. Using the percussion method of boring, it was found practicable to complete one section 20 feet deep in about eight hours. The majority of the borings were not more than 7 inches out of plumb, and this method of pile-sinking was found to be very satisfactory. A complete description of the work may be found in the *Engineering News-Record* for 8th February, 1923, from which the above details have been extracted.

The passages for the tying-down bolts of the bridge of La Roche Bernard were also formed by boring. Indeed, boring is applicable either under water or on dry land, either in a vertical, horizontal, or inclined direction; and though its cheapness is most apparent when the hole is comparatively small, yet it is sometimes practised of a diameter of many feet, if the situation should not admit of excavation. Such a case as the above is frequently to be met with in well-work; thus in sinking iron cylinders through sand charged

with water, the water must either be pumped out or the sand bored through. The latter will always be chosen when the rush of water is great, or when the pumping becomes expensive. To enumerate every case in which boring can be successfully applied would be useless; its capabilities for various purposes, whether for wells, for draining, mining, building, or purely scientific purposes, being now ascertained, every engineer can judge of the circumstances which should dictate its adoption.

Another little-known application is the formation of "absorbing" wells, by means of which waste water might be removed, or a depleted ground-water supply replenished by sending the water down to an absorbent substratum (see p. 88). The process is generally uneconomical, and is only recommended to be carried out in exceptional cases under competent direction and after a thorough investigation; but some curious natural laws have been divulged by the experiments to which such works have given rise.

Thus, it has been proved that a well can absorb a quantity of water equal to what it yields. If, for instance, a boring yield 100 gallons per minute, and the water cease to ascend at 3 feet above the ground, by merely lengthening the tube 3 feet in addition above the permanent level of the water, 100 gallons may be continually poured in per minute without flowing over the orifice of the tube. If it be desired to make such a boring absorb say 500 gallons per minute, a pump able to raise that quantity is inserted in the well, and notice is taken of the depth to which it can lower the water-line. If we suppose it to be 15 feet, for instance, it will be sufficient to place a column of that length above the water-line, and the boring will absorb the quantity of 500 gallons. Should the water-line be below the surface of the ground, the absorption by this description of well may be indefinite.

Care must be taken to prevent any solid matters in suspension in the waters proposed to be absorbed from being carried into the boring, or they would rapidly choke it up. Precautions also require to be taken to prevent the contamination of neighbouring wells.

It appears upon a retrospective glance at the history of well-sinking, that its principles of execution are unchanged,

but that the practice is by no means so; and that, both as regards their mode of construction and materials, considerable modifications have been introduced. Wells may be divided into two classes, i.e. dug wells and artesian boreholes. The former, which are rarely constructed now, are dug, necessarily of considerable diameter, through the strata near the surface, to the spring itself, and are supplied by the filtrations of the immediate locality; the latter (named after the province of the Artois, where, as we have seen, they have been resorted to for many ages) are not dug, but bored through such retentive upper strata as may overlie a permeable stratum, the outcrop of which is at a sufficient height to produce a hydrostatic pressure upon the springs sufficient to make them rise in the tube of the bore.

In carrying on boring and well-work, a great deal of practical information applicable in other operations, and interesting in reference to the one going on, may be embodied by keeping a correct journal. The one given here is the type used by Messrs. Isler & Co., London, by whom it was kindly supplied. In addition a chart is kept which shows the exact thickness and depth below ground level (or ordnance datum) of each strata penetrated. If required a record may also be kept of the tools used day by day and the number of journeys by each, for the information so obtained is valuable in determining costs and as an assurance that the tools are being used economically so that productive work is proceeding at the bottom of the borehole for a satisfactory proportion of the total working time.

It is important that these records should be accurately kept up to date, for a great deal of valuable information may be obtained from them concerning the actual work in progress. Also, when compared with other data, the journal is invaluable in augmenting the geological information of the neighbourhood, particularly regarding the relative rise and fall of water-level in the district. In many parts of the country such information is, even yet, quite inadequate.

As the boring proceeds samples of the water found should be taken, together with a note of the depth, and analyses should be obtained, so that the exact character of the water may be known and undesirable waters excluded.

BORED TUBE WELL DAILY REPORT.

Name of Person or Firm for whom Well is Bored | *Date* 192

Nature of Strata	feet of inch pipe	top feet {above/below} surface	Materials required
No. of feet bored to-day size of tool ..			
Total depth bored .	" " " "	top feet {above/below} surface	... .
Total depth from surface .			
Depth water below surface in bore tube:— With rods in	" " " "	top feet {above/below} surface	
" " out .			... ...
Depth water below surface in dug well	Yield in Gallons per minute		
Depth of dug well ... ... Size			
Depth of Boring Stage below surface .			

REMARKS:— Foreman and . men.

Time commenced Time left off ... .

Signature

N.B.—All particulars for which spaces are given at the head of this Report must be filled in daily, even though unchanged.

CHAPTER II.

THEORY OF SPRINGS.

FOR many years there has been considerable difference of opinion among engineers causing much discussion on the theory of springs. The explanations which have been offered of the phenomena they present have been innumerable: some were partially true, and applicable in certain cases; some extremely absurd. It would be beyond the province of this work to relate the steps by which our knowledge upon this subject has progressed, and it may therefore be sufficient to state that it is now definitely established that the explanation of the flow of water from springs, whether deep-seated or superficial, is to be found in the fact that they are the lines of natural drainage; in other words, that they are supplied by the rain, hail, snow, and vapour precipitated upon the earth's surface, and part of which is absorbed thereby. A vast circulation of water is thus kept up. The rivers and streams, supplied by springs, in their turn contribute to supply the sea, which, together with the water generally, supplies the atmosphere by its evaporation, and thus completes the circuit. Though it has never been denied that land-springs, that is to say, springs found near the surface of the ground, are supplied by rain—indeed, the fact speaks for itself, inasmuch as in dry weather they often cease to flow—yet, that deep well-springs are supplied from the same source was disputed; for, said the objectors, how is it that an increase of rain apparently makes no difference in the quantity of water, and, in like manner, drought appears not to affect them? A satisfactory answer to this will be found in the examination of the circumstances affecting such springs; it will be seen that they are generally derived from reservoirs of porous matter interposed between impermeable strata, which reservoirs will naturally overflow at the points where the permeable strata, supposing them to assume a basin-like form, touch the surface of the ground. The waters which overflow at these points form rivulets and streams, and the effect of great rain or drought will be only to add or to diminish

the quantity discharged by these natural channels; whilst little difference will be found in the height of the water-line in the main reservoir itself. The word *little* is used advisedly, because it has been shown by careful experiments that a slight difference does generally exist according to the different seasons of the year.

The original source of all water supply is the moisture, including rain, snow, dew, etc., which reaches ground level, and it is the character of the surface which determines the future course of this moisture.

In the first place a part flows off by natural channels, eventually forming rivers and reaching the sea.

Secondly, a part is returned directly to the atmosphere by evaporation from either land or water surfaces. In this connection a part may also be included which is taken up by vegetation and for the most part returned to the atmosphere.

Finally, a part percolates into the ground beyond the reach of vegetation to supply underground sources, and appears at the surface again at a lower level in the form of springs.

A more detailed examination will show that the proportion of the total moisture available at ground level which follows any one of these possible routes depends on:—

(*a*) The nature of the surface.
(*b*) The inclination of the surface.
(*c*) The rainfall and climate.
(*d*) Vegetation.
(*e*) The quantity of water already present in the ground.

The dry weather flow of a stream is normally equal to the percolation over the area of its watershed. The total flow is equal to the percolation together with the run-off reaching the stream by natural channels on the surface of the ground, minus the evaporation. Heavy rains will increase the total flow owing to increased run-off, but the percolation will remain about constant and may decrease if the ground becomes saturated. If considerable quantities of water are taken from the ground by means of artificial wells there may be a reduction in the dry weather flow of any stream in the neighbourhood of the wells.

The run-off to streams is increased by a very fine soil or by a hard, impervious or steeply inclined surface; for under

such conditions the water cannot percolate into the ground, and flows off more quickly than it evaporates, so that both percolation and evaporation are small.

The correct determination of evaporation from land surfaces presents many difficulties. It is dependent upon the nature of the surface soil, vegetation, the amount of moisture present in the soil and temperature, and may have the effect of extracting the moisture from the ground up to three feet or even more below the surface.

In Great Britain the average amount of evaporation is about 12 to 15 inches per annum (or about one-third of the average rainfall). Various experiments have been made from time to time to obtain exact formulæ for evaporation, but nothing very reliable for general application for land surfaces has been proved yet, although accurate information is available for water surfaces.

Wherever the percolation is large it may be taken that the evaporation will be small in comparison, while the ideal conditions for evaporation are a level surface and fairly heavy or impervious soil which retains the moisture near the surface and within reach of vegetation. Crops will absorb large quantities of moisture which would otherwise percolate and reach the ground water supply. Thus Risler estimated that wheat, oats, clover, etc., would absorb between 12 and 15 inches of water between seed time and harvest and grasses 30 to 40 inches during the summer, while Baldwin Latham found that Italian rye grass would absorb more than 100 inches if the supply was available.

Finally, it is usually found that a large rainfall is accompanied by a large evaporation.

The chief factors influencing percolation are rainfall and the character of the surface soil and underlying strata. If the surface is of an absorbent or permeable nature the percolation will be relatively large and the run-off and evaporation will be small since the moisture is absorbed by the ground as it falls, thus allowing no opportunity for evaporation. A coarse or sandy soil is most favourable. On a steeply inclined surface the water will quickly flow off by natural channels, probably cutting its own path, and the percolation will be small. In a hot climate or thickly vegetated district the evaporation will be large and the percolation proportionately small.

Forests have been proved to take up less moisture than crops, and as they tend to retard surface flow and decrease evaporation there is often increased percolation over afforested areas.

Some experiments carried out at Rothamsted some years ago showed that with an average annual rainfall of 30·29 in. the average annual percolation was 13·61 in. (*Proc. Inst. C.E.*, vol. cv, p. 31). These experiments were on a small scale, and there was no run-off, but experience generally shows that with an average rainfall and a loamy or sandy surface soil about 3 feet thick with moderate vegetation and porous underlying strata the percolation amounts to about 40 per cent of the rainfall. This may be subject to considerable variation during the year, and under extreme conditions of surface soil and vegetation.

With a coarse soil and permeable underlying strata the ground water flow is usually large and constant, but if the surface is of an impermeable nature the ground water supply will be small, unless water gravitates below the impermeable strata from outside sources.

These considerations will evidently have a considerable effect upon the percolation and available ground water for wells or borings, and an estimation of the principles of ground water supply should now be possible.

The water forming the supply which is tapped by any boring or well is, then, that which escapes evaporation and does not form a surface stream, but percolates down beyond the reach of vegetation until an impermeable strata is reached. Here the progress of the water in a vertical direction is impeded and the strata immediately above becomes saturated until a level is reached at which the water can escape laterally either at ground level or through a fault in the geological formation into another permeable strata. The surface of the water is called the "Ground Water Level", and varies with the volume of water reaching it. The variation in level may amount to some feet between times of great rainfall and times of drought.

A partial examination of the strata of a district at one time led to the belief that springs could not be fed by rain falling on the earth's surface, because the latter, in the point immediately above the springs, is separated from

them by clayey or rocky strata impervious to water. This objection is of no weight, for it does not follow that because the latter are supplied by absorption from the earth's surface, therefore the rain must sink into it vertically, any more than in the case of a common water-tank, where the water is conducted by pipes from an exposed surface to a reservoir. Now, if in the simile we substitute porous strata beneath impervious ones for the pipes, and suppose that the former are exposed to the rain at some distant points, an explanation of the whole matter is at once suggested. It will be found that the existence of numerous springs may be accounted for on this supposition and that it also serves to explain the difference between land-springs and those called deep-seated.

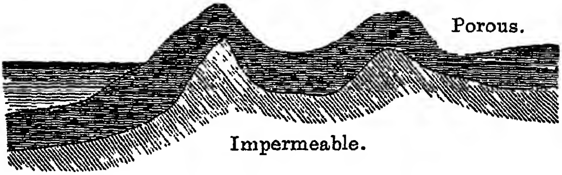
When the surface of a particular district consists of a loose permeable material lying upon a retentive substratum, the waters soaking through from above will descend until they meet with the obstacle it offers to their further descent. As such waters are not under any hydrostatic pressure, they cannot rise above the ground, and, on the contrary, they rush into any artificial depression in the upholding bed : such sources of water are called land-springs.

Deep-seated springs, on the contrary, are those fulfilling more exactly the conditions we have supposed. Their supply is derived from the rainfall upon the surface of the porous strata, situated at a high level, passing under an impermeable stratum, which soaks through them until it meets with a retentive substratum , and then, if it cannot find, or make, an outlet, the water follows the lowest levels of the permeable strata, according to the laws which regulate its flow above ground. If, under these circumstances, an opening be made through the overlying impermeable stratum, the water will rise to a height corresponding with the hydrostatical pressure upon it, excepting insomuch as it may be affected by the friction it meets with in its traject, or by the existence of any natural overflows. All Artesian wells are supplied by springs of this kind.

These general principles may be explained by reference to the Figs 1 to 6. In Fig. 1 a porous stratum is represented lying upon an impermeable stratum, and in this case a little reflection must show that the waters would

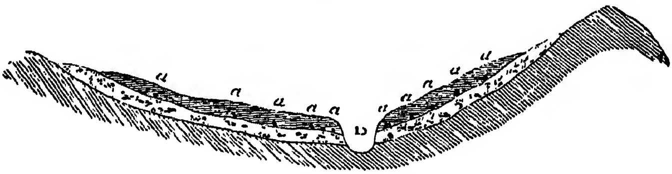
collect at the lowest points of the depressions upon the top of the latter; and that if wells were sunk into this, the

FIG. 1.



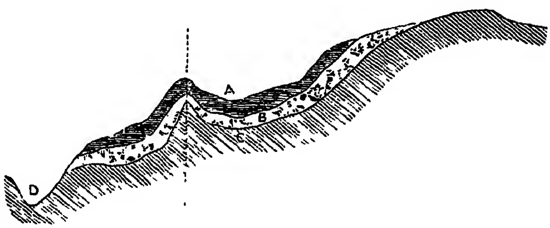
water from the upper stratum would flow into them. In Fig. 2, if we suppose the permeable stratum upon the sides of a hill to be covered by an impermeable stratum *a a a*,

FIG. 2.



and intersected by a ravine or a water-course, it must be clear that the natural tendency of the waters falling upon the outcrop of the permeable stratum would be to descend to the ravine, unless a readier vent were offered at a higher

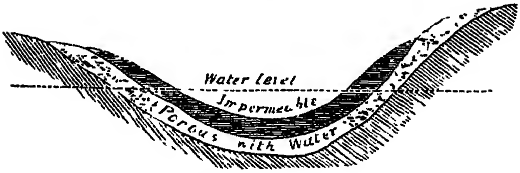
FIG. 3.



point. In Fig. 3, a portion of the waters would accumulate at C until they rose to a level above the projecting spur in the substratum: as soon as they passed this, they would begin to flow over towards D, and acting as in a syphon would effectually drain the intermediate porous stratum.

In Fig. 4 an illustration is given of the phenomena presented by the alternations of permeable and impermeable strata in which no ravine or water-course occurs to alter the normal

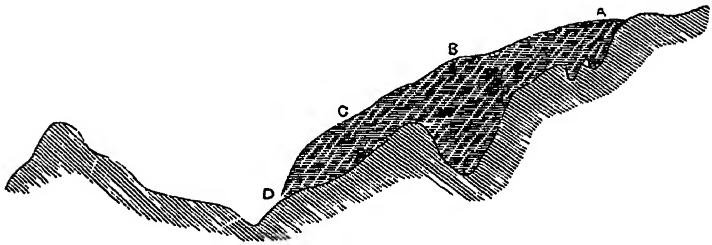
FIG. 4.



Impermeable.

conditions of the water-line. Fig. 5 is an illustration of the appearance often presented by the chalk formation covered by the drift gravel; in this case the bulk of the water would lodge in the depression below B.

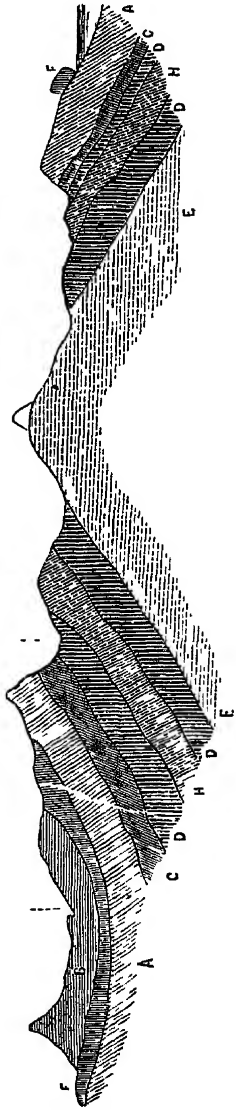
FIG. 5.



In Fig. 6 is represented an ideal section of the London basin, showing the configuration of the strata, which serves to account for the supply of the numerous deep wells in the metropolis. All the water, falling upon the outcrop of the plastic clay and sand, passes under the impermeable blue clay, and if it be not afforded vent by wells sunk through the latter, it passes through the chalk, together with the waters falling upon the outcrop of the latter, until they meet the retentive strata of the chalk marl, or until they rise to the surface by any natural vent.

The underground water in the London area is discussed more fully in Chapter VI, from which it will be seen that the

Fig. 6.



Cross Section of Part of the London Basin.

A Upper and Lower Chalk.
B London Clay
C Chalk Marl and Fire-stone
D Blue Marl
E Iron-sand.
F Plastic Clay and Sand.
H Green-sand.

above stratification results in a gigantic reservoir under the metropolis.

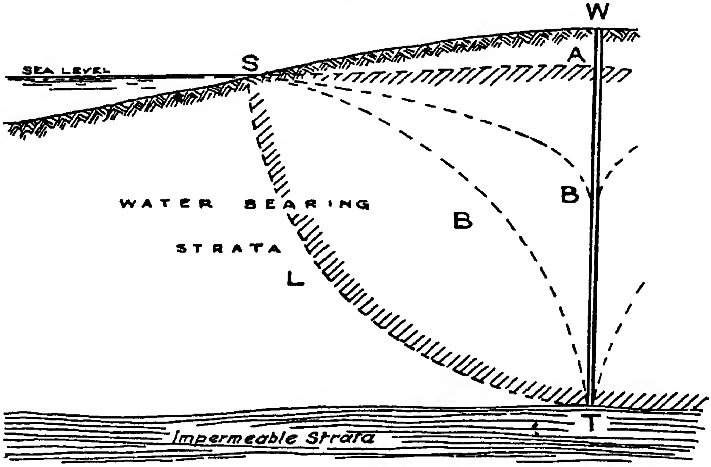
Some fresh-water springs receive a supply from, and are modified by, the waters of the sea, derived thencefrom by gravitation or capillary action. When the sea rests on porous matter, as chalk, no reason can be given why the water should not be absorbed by it, and affect to a certain extent the quantity and quality of drainage water which may be held in the same chalk reservoir ; and this more especially when the water-level of the springs is at or below the level of the sea. It is natural to suppose this action would be felt to the greatest extent near the sea itself—a supposition borne out by facts. For instance, a well sunk at Newhaven, in the chalk, yielded water which was seriously affected by the percolation of the sea. Reference to a geological map will show that those same chalk hills, as well as others abutting on the sea, are continued without interruption to the main chalk range on the western side of the London basin ; therefore, in a modified degree, the percolating action of the sea water must be felt in all parts of the basin at or near its level, and which are not cut off from this action by any uplifting of the strata under the chalk, as in Fig. 1.

In practice the effect is negligible if the strata is far removed from the coast. At the same time, many wells in the Magnesian Limestone, Chalk, Greensand, and New Red Sandstone formations have been abandoned owing to their excessive saline properties. But the upper chalk particularly is quite porous and recent research shows that sea water will penetrate through permeable strata under normal conditions for only a short distance. The penetration will be increased by heavy pumping or any other conditions which lower the ground water level, and will also be appreciable further inland in a dry climate than in a humid one. Normally the saline contents will not be excessive if the depth of the boring is less than its distance from the coast : i.e a boring 1,000 feet deep below sea level should be at least 1,000 feet from high water mark. The ebb and flow of tides appears to have but little effect upon salinity.

A theoretical conception of the incidence of sea water may be represented as in Fig. 7. Suppose a well be sunk at w

in porous strata bounded by the sea. The normal ground water line will be approximately S A and the shaded area will represent the limits of fresh water, since the denser sea water will tend to keep below the fresh water. So long as the curve of depletion in the well is in the form S B, the water will be satisfactory. But if it approaches the line S L T, the water

FIG. 7.



Penetration of Sea Water.

will possess excessive salinity. Many factors will, of course, occur to produce variations from any ideal rule, such as the above, which only represents the principles of the penetration of sea water.

Strata of England and Wales in reference to their Springs.

The most superficial observer must be aware that the components of the surface of the earth vary greatly in different situations; in some places hard, crystalline, unstratified rocks make their appearance; whilst in others soft strata, evidently bearing the character of having been deposited in layers, will be found. Closer examination will show that this disposition is not the result of an accidental confusion, but follows from an order of superposition which it has been the province of geology to ascertain.

The purport of the present chapter is to lay before the reader the relation of these various substances composing the earth's crust, as connected with the subject of springs; and because the surface of the crust may be taken as an index of what may be expected underneath, it is desirable to give the order in which the various rocks and deposits are found. The reason that in all cases the same distance does not intervene between the lower rocks and the earth's surface is simply from the fact of the inclined, and not horizontal, position of the strata; and the alteration in the position of the strata may easily be traced to disturbances of a subsequent date to their deposition. Although the lower rocks outcrop and show themselves in many places on the earth's surface; and further, though some usually intervening rocks may be, and often are, missing between some of the upper and under beds of the series, yet, except under very unusual circumstances, none of the upper ones will underlie the deposit or rock which the order of superposition usually places them above. Descending from what geologists consider the latest formation, a section of the earth's crust may be represented as follows, a great many subdivisions being of course omitted.

Recent, Pliocene. Oligocene, and Eocene Formations.—Vegetable soil and alluvium gravel, sand, drift, plastic clay, Bagshot sands, London clay, Thanet sands.

Cretaceous System.—Chalk, chalk marl, upper greensand, gault clay, lower greensand, weald clay, Hastings beds.

Oolitic Group, Upper Series.—Purbeck beds, Portland beds, calcareous sand, Kimmeridge clay.

Middle Series.—Coral rag, yellow sands, calcareous-siliceous grits, Oxford clay.

Lower Series.—Cornbrash limestone, and forest marble, great oolite, or softish freestone, layers of clay, Stonesfield slate, fullers' earth, clay, sandy limestone.

Liassic Group—which consists of limestone beds, divided by layers of clay.

New Red Sandstone Group—consisting of Keuper marls, Bunter sandstones, conglomerates, gypsum, rock salt, bone red or dark-coloured limestone, blue and blackish limestone, alternating with clay and marl, etc.

Magnesian Limestone.

Carboniferous Group.—Coal measures, sandstones, clays, shales, ironstone, millstone grit, mountain limestone.

Devonian System.—Old red sandstone, slates, and grits.

Silurian System, comprising argillaceous limestones, sandstones, quartzose flints, flagstones, schist.

Cambrian System, or inferior stratified rocks of clay slate conglomerates, with dark-coloured limestones, sandstones, etc.

Archæan and Pre-Cambrian Rocks.—Granite, syenite greenstone, hornblende, etc.

Water-bearing Qualities of these Strata.

It is not here intended to explain the properties of the various substances mentioned above, excepting so far as they are connected with the consideration of springs in them. The vegetable soil comes first under review; such soil, if it rest on gravel or sand, will always be dry; but if it rest on clay, or any other retentive strata, will, unless well drained, be a complete swamp; on such a substratum rest those soils where the springs are within a few feet of the surface; should, however, gravel or sand succeed the surface soil no water can be expected in it till a retentive seam of clay or other impermeable matter be met with. When sand, as at Hampstead, rests on London clay, very little difficulty is occasioned in getting a water supply from it; but such land-springs are, from their nature, very variable.

Gravel oftentimes rests on porous chalk, in many parts of Hertfordshire, for instance; in such positions no water can be expected to be met with in wells in the gravel, but they must be sunk to the saturated point of the chalk.

In the London clay formation there are few springs, and though by chance one may be met with, nobody would think of sinking a well in the London clay in full anticipation of getting water till that formation was passed through, and the beds of sand in the plastic clay formation were entered; in these there is a very copious supply.

The quantity of water held in the cretaceous group is enormous; the lower portion of the chalk itself, as far as the denseness of the material will allow, is fully saturated; all fissures in it are completely full, forming literally subterranean rivers. The strata directly under

the chalk, consisting of retentive marl, will make it appear clear to all why the lower portions of this formation should contain so much water. The long lines of flint in chalk have been remarked on before, as favouring the percolation of water, and so has the fact that, in the London chalk basin, those circumstances exist that are required to insure the success of sinking artesian wells. When wells are sunk in the lower greensand formation, water may be met with where clay seams occur; the water which supplies the deep-seated springs is held up by the weald clay under the sand. The water supplied by the iron sand is generally arrived at by sinking deep wells; but it is often impregnated with iron.

In the upper oolite system little water can be expected in the impermeable beds of Purbeck and Portland stone, except in fissures; under the Portland bed, however, is porous matter, and the water absorbed by it is retained by the underlying clay, thus rendering it accessible. In the middle oolitic series, the Oxford or clunch clay is the retentive medium, and wells must be sunk to the saturated portions of the overlying porous matter. In the Oxford clay itself are few springs. The lower oolitic formation has water retained by clay seams. In the cornbrash limestone and forest marble the wells are not very deep; under the great oolite, the fullers' earth clay retains the water. The limestone itself is porous to a certain extent, therefore wells must be sunk in it to its line of saturation, or its junction with the clay underneath.

The upper retentive beds of the lias formation supply water to the wells sunk in the lower oolite; and water may be met with in the upper portions of the lias formation for the same reason. Wells sunk in the lower portions of the lias formation have water retained in them by the upper marls of the new red sandstone group.

The alternations of sandstone and clay, rock salt, etc., in the new red sandstone, render water procurable in that group. Records of a shaft sunk in this formation in the north of England some years ago relate that from a well 70 yards deep with radiating galleries from the main shaft, the quantity of water raised amounted to 2,000,000 gallons per day.

In the magnesian limestone, fissures and holes con-

taining water must be worked for. The great quantity of water in the carboniferous group is probably known to all, it being an element which, were it not for the large pumping engines constantly at work, would greatly impede the operations of the miner; the alternating porous and retentive matter in this formation fully accounts for the appearance of the water. The mountain limestone being porous, water can only be met with when beds of clay occur; the lower portions, however, of this formation are saturated, because impervious layers separate it from the porous beds of the old red sandstone. In this latter formation there is no lack of water, its components being partly porous, with retentive intervening layers.

Owing to the stratified character of the Silurian system, water may be met with in it; and in the lower Plutonic rocks, where they show themselves at the surface, the only chance of getting water is by sinking till a fissure fully charged with water is arrived at.

The geological strata that occur in other parts of the world generally correspond in series and order to those in Great Britain, although local nomenclature may be used.

The following is the usual classification of the strata of Great Britain into five periods:—

(i) *Anthropozoic or Quaternary Period.*—Recent and Glacial deposits.

(ii) *Cainozoic or Tertiary Period.*—Pliocene, Oligocene, and Eocene formations.

(iii) *Mesozoic or Secondary Period.*—Cretaceous, Jurassic (including oolitic and liassic series), and Triassic systems.

(iv) *Palæozoic or Primary Period.*—Permian (including the Magnesian Limestone and the New Red Sandstone Group), Carboniferous, Devonian, Silurian, and Cambrian systems.

(v) *Eozoic or Archæan Rocks.*—Metamorphic and Igneous Rocks.

CHAPTER III.

YIELD OF WELLS.

Before examining more particularly the various circumstances affecting the supply of water to springs, some peculiar examples may be quoted.

Among these the hot springs of Iceland are interesting. The Great Geyser issues from a perpendicular well about 10 feet diameter in the centre of a basin which is usually covered to a depth of about 4 feet with clear hot water. During eruption a few small jets first appear, becoming gradually larger until there is one jet only, equal to the diameter of the well and 50 or 100 feet high. Eruptions last but a few minutes and occur at intervals seldom exceeding many hours.

The fountains of Vaucluse and Nimes are remarkable on account of their volume. The former yields between 100,000 and 300,000 gallons per minute in a dry or wet season respectively, while the latter is interesting because, if there is any rainfall on the north-west of the town, it has the effect of increasing the yield about tenfold almost immediately.

There are many cases of freshwater springs rising in the sea, notably one in the Gulf of Spezzia, which forms a dome upon the surface of the sea about 90 feet in diameter with an elevation of about 16 inches at the centre. It is composed of a number of vertical jets which are very perceptible when the sea is calm.

Choice of Site for Boring.

Considerable difficulty often arises in determining the exact and most favourable position for a boring.

If it is known that the boring must necessarily be deep to reach the ground water, the quest resolves itself into a matter of experience and judgment, but for springs or flowing water near the surface there are other indications which may prove valuable. "Water-divining" has recently received much attention, and although it is not possible to give here a long description of the art of "dowsing", yet it is well to mention

that abundant proof is available to show that this method is a reliable means of detecting the presence of flowing water near ground-level. Many theories have been formulated to explain the phenomena but no proof is yet available.

There are additional indications which may lead to the discovery of springs in cases where nothing would appear, to those unaccustomed to observations of natural phenomena, to induce a belief in their existence. The following are some of the most simple.

In the early part of the year, if the grass assumes a brighter colour in one particular part of a field than in the remainder, or, when the latter is ploughed, if a part is darker than the rest, it may be suspected that water will be found beneath it.

In summer, the gnats hover in a column, and remain always at a certain height above the ground, over the spots where springs are concealed.

In all seasons of the year, more dense vapours arise from those portions of the surface which, owing to the existence of subterranean springs, are more damp, especially in the morning or the evening. It is for this reason that the well-sinkers of Northern Italy go in the morning to the places near which it is desired to sink a well; they lie down upon the ground, and look towards the sun, to endeavour to discover the places in the neighbourhood from which denser vapours may arise than from the rest of the field.

The springs to which these rules apply are such only as are near the surface; when the source is lower, they are rarely sufficient, and the only safe guide is a boring; but to execute such operations with any chance of success, a certain knowledge of elementary Geology is absolutely necessary.

Provided that the sources do not descend to any very great depth, the principle *that subterranean waters follow precisely similar laws to those upon the surface* holds good; but when they are very deep-seated, many disturbing causes, to be noticed hereafter, modify their action. If, in a valley formed in a diluvial or alluvial deposit lying upon a more retentive stratum, the two sides are of the same height, the water must be sought in the middle; and if, on

the contrary, one side be steeper than the other, the stream would pass near the steeper side; in both cases supposing that the materials of the upper stratum are equally permeable throughout, and that the depression of the lower stratum presents a tolerably regular basin-like depression. Springs are not often to be met with at the head of valleys, but they are much more frequently to be found at the intersection of the secondary valleys with the principal one; and the most favourable point for finding water is usually that which is the furthest from the intersection of these valleys, and in the lower parts of the plain succeeding them, at precisely those positions where there is the least water upon the surface.

When the transverse valleys, giving forth streams to a river in the bottom of a longitudinal valley, are nearly at right angles to the direction of the latter, the quantity of water they yield is much less than when they form an angle with it. This law holds good equally with subterranean and with surface waters, and it may therefore be laid down as a maxim that the most favourable point for seeking a supply by a well would be at the mouth of long transverse valleys inclined to the principal one.

When, as we have before supposed, and as in fact occurs in the London basin, permeable strata are exposed over a great surface of country, and pass under more retentive ones, whilst at the same time they themselves lie upon others of that nature, by the usual laws of hydrodynamics the water falling upon their outcrop will descend to the lowest level of the basin, nor will it begin to overflow until the whole of the depressed portion is saturated. A boring through the upper stratum will then become filled by the water from below to a point corresponding with the altitude at which the waters are maintained in the basin by the natural overflows. These abstract principles, however, are only applicable when the basin is not disturbed; and it is particularly to be noticed that the existence of any large fissure in the external ridge of the basin, giving passage to a water-course, will be found to regulate the height of the waters to a very considerable distance from it on either side. If, however, any extensive fault exist in the bottom of the basin, by means of which the permeable stratum

should be placed in communication with any other of a similar character, the waters will necessarily flow into the latter. The success of a boring for an artesian well depends, in fact, so far as the mere retention of the waters is concerned, upon the perfection of the basin formed by the upholding stratum; and, so far as the height of the water-line is concerned, upon the level of the streams flowing from the water-bearing stratum.

The value of an underground water supply can only be determined by experiment, but an expert will usually be able to give a fairly accurate estimate of the amount of water likely to be available. A knowledge of the geological formation, together with details of the rest-level in other wells in the neighbourhood, will afford valuable information. Allowance must be made for friction due to the flow; the hydraulic gradient will be steeper through a dense formation than through an open one. Thus Dr. D. Halton Thomson, M.A., found that the water took up a much steeper gradient through the middle and lower chalk than in the upper series; in fact, there was a well-defined change of gradient as the water-line passed from the middle to the upper chalk. There may be considerable variation of water-level even in a small area, particularly in the older water-bearing formations, chiefly due to faults in the geological structure. With the most elaborate investigation and the most extensive knowledge, there is always a degree of chance about the first well bored for the purpose of reaching deep springs in any district. It is not, therefore, surprising that the majority of the early attempts made in our country should have been failures.

The remarkable success of the Artesian well of Grenelle inspired a fever for undertaking others of a similar nature; but it does not necessarily follow that if a boring be carried through the chalk into the greensand, the water will rise above the ground. In the first place it is to be observed that in the Paris basin the supply for the wells of Elbœuf and of Grenelle is derived from the lower greensand which lies upon the retentive strata of the Wealden, and that it enters the sand at a point very much above the position of the wells, as also that the last considerable streams from the greensand are at a much higher level than the same position. Similar borings near Calais were failures; for the sub-

cretaceous formations there repose upon the carboniferous strata, without the interposition of the oolites, the lias, or any of the intermediate series. In this case the only chance of success would have been in finding some depression in the older formations filled with water, but of course it could never rise to any useful height.

A well at Southampton afforded also some very important lessons with respect to the disturbances or modifications likely to be met with in the prosecution of such works. It was commenced at a point about a mile and a half from the sea, and 140 feet above the level of the high tides. As too frequently happens, no survey of the entering ground of the greensand formations was made before commencing it; nor were the disturbances of the chalk strata, the only ones exposed in a manner able to furnish any valuable indications, taken into account. Now it happens that the greensand ridge is disrupted in several places on the edge of the basin supposed to hold the waters from which the well was expected to be supplied, and important rivers flow away from it at those places, at levels little above the ground at the well. Should a water-bearing stratum exist, therefore, the water can rise very little above the ground, even supposing that all the other necessary conditions be fulfilled. But the whole of this part of the country has been disturbed in a very remarkable manner. A very strongly marked fault exists in the chalk near Winchester, and continues to the sea-shore near Portsmouth. The sea has formed two large breaches in the containing basin of the greensand on the east and west of the Isle of Wight. At the back of the island the marks of geological disturbance are even more evident than upon the north of Southampton, the strata are contorted, and even tilted up in a vertical direction. The same facts occur also more to the south-west, near the Isle of Purbeck, so that there appears little reason to believe that the basin is continuous; and at any rate the sea is in direct communication with the greensand formations: if, therefore, it does not affect the quality of the water contained in the greensand, it must regulate the water-line, and cause it to take a regular inclination corresponding nearly with a line drawn from the last great inland overflow to the sea water-level. But it was found

that the water obtained from the chalk itself as the work progressed was strongly affected by the infiltration through the body of the rock from the sea. If this be the case with a substance comparatively so dense as the chalk, the probability that the same effect will take place with the more pervious materials of the subcretaceous rocks amounts almost to a certainty.

Again, in all cases where wells have been sunk to a great distance from the surface, it is known that at a certain point the temperature becomes constant, and that beyond this it increases according to a law susceptible of modification by local circumstances. The allowance usually made gives the mean rate of increase in Great Britain as about 1° Fahrenheit for about 57 feet of descent. M. Walferdin found in Paris the increase was at the rate of 1·8 Fahrenheit for every 102 ft. 10½ in. (or 1 centigrade for 30 m. 87). M. de Girardin found at Rouen that it was about 1·8 for 67 ft. 4 in. in one case and 1·8 for 100 feet descent in another; whilst the more accurate experiments upon the Artesian well of Grenelle showed that the increase there was with remarkable regularity 1·8 Fahrenheit for 106 feet descent below the point of constant temperature, which was about 93 ft. 6 in. from the surface of the ground at the Observatory of Paris, and marks a little more than 53° Fahrenheit. This would give an increase of temperature of about 1° Fahrenheit to 59 feet descent. This important law unfortunately was for a long time neglected in England, or certainly, as in the case of Southampton, the notion of obtaining the whole supply of the town from a deep-seated Artesian well would never have been entertained. This boring was carried to a depth of 1,320 feet nearly, still in the chalk, so that even did a supply of soft water exist at that depth, it would have a temperature of nearly 75° Fahrenheit. From these combined reasons, the inhabitants of Southampton eventually abandoned the boring on their Common—unfortunately not before they had spent a very large sum of money upon a work which, if a survey of the district had been made by a competent engineer, would never have been commenced.

The secondary rocks frequently give off powerful springs without any apparent indication of the existence of the interchange of strata we have hitherto considered. Well-

known instances of this occur in the springs from the chalk near the head of the New River at Chadwell and Amwell, at Otterbourne, near Southampton, and at several other points in the valleys of the great chalk mass of the south-west of England. It will, however, always be found that these springs occur in valleys much below the general level of the formation, and their overflow usually corresponds with the existence of some fissure above a harder and more retentive bed than the mass of the chalk. The same remark holds good with the oolites and the lias; but in addition to the inequality of texture in the bulk of the formation these particular ones are more likely to throw off springs, owing to the existence of numerous intercalated beds of stiff clay. It rarely happens, however, that these retentive strata can be traced with certainty over a sufficient area to warrant the commencement of any expensive works upon them.

The primary rocks are even more unfavourable than the older secondary rocks for ascertaining, by any abstract rules, the existence of springs. Their stratification is rarely persistent over a great extent of country, and the permeable materials, forming as it were filters, so seldom exist as to make the occurrence of deep-seated springs very rare. Water may permeate these rocks in their numerous fissures, but necessarily it is impossible to predicate what may be their direction, or what conditions of hydrostatical pressure may exist.

Much valuable data has been published regarding this by Mr. E. O. Forster-Brown after prolonged investigations of underground water in the Kent Coal-field ("Underground Waters in the Kent Coalfield and their Incidence in Mining Development," by E. O. Forster-Brown, *Proc. Inst. C.E.*, vol. ccxv, 1923, p. 27). Considerable variation was found both in presence and volume of water over a comparatively limited area.

If many Artesian wells be sunk in the same stratum and be supplied by the same deep-seated springs, it becomes necessary to ascertain the rate of inclination of the water-line before any exact conclusions can be arrived at with respect to the definite results of a new boring. Of course, as the outcrop of the water-bearing stratum is only exposed

over a certain area, the quantity it can yield must be limited; and for the same reason, if much water be withdrawn at a high level, the lower wells must suffer. That this is a real danger is proved by the state of the wells near London supplied by the water filtering through the plastic clay. So many have been sunk, that very few of those which formerly overflowed the surface now rise to within some distance of it, and the volume yielded is also considerably reduced. The wells in the chalk near London are also producing the same result, and the water-line is annually lowering. The Rev. J. C. Clutterbuck, of Watford, who paid great attention to this subject, found that the water-line of the chalk near London had a general inclination of 13 feet in a mile upon a line drawn from Watford to the Thames, until Kilburn is reached, where there was a depression owing to the pumping around London (see also p. 105). North of Watford, the rate of inclination was found to amount to 200 feet in 14 miles, but it was affected by the degree of saturation of the lower strata. In the Hampshire chalk basin, the rate of inclination has been stated to be 13 feet in a mile; so that numerous local circumstances require to be taken into account before any decided opinion can be arrived at upon this point, and equally numerous observations are requisite to furnish the elements of any reliable reasoning upon the subject. In the last-named geological basin, however, it is more easy to observe the phenomena attending the inclination of the water-line, because there is little pumping at the lower end to interfere with its normal condition. From the well at East Oakley (about 16 miles from Southampton) the water-level, which is there about 302 feet above the Ordnance datum, lowers to about 100 feet at the well upon the Southampton Common. But the rate at which the water-line lowers is far from being regular; it is more rapid near the summit, more gradual near to the coast, and may be represented by a parabolic curve. There are local irregularities occasioned by the outburst of considerable springs, due probably to some dislocation of the strata; but the general inclination prevails with tolerable regularity.

Stated generally, the laws regulating the height to which water will rise in an Artesian well are as follows: it will

rise to the height of the point of supply, with a diminution caused—firstly, by the loss of some portion of the water through fissures; secondly, by the friction it meets with in traversing the water-bearing stratum; but it must always be borne in mind that the existence of a large natural overflow will lower the general water-line to its own level.

The phenomena of intermittent springs may be explained upon the principle that underground waters follow the same law as those flowing upon the surface; if a natural syphon be supposed to communicate with some subterranean basin, and it discharge the water more rapidly than the supply arrive, the reservoir will from time to time be so lowered that the syphon will cease to act. Under these circumstances the flow will be interrupted until the water rises again in the syphon to a height sufficient to cause a recommencement of its action. This alternation of flow will happen at intervals corresponding with the proportion between the capacity of the supply and of the discharging syphon. And finally we may state that no apparent anomalies exist which may not be explained by the geological and hydrodynamical considerations above detailed.

General Principles of the flow of Underground Water.

The flow of water into an underground well is governed by similar laws to those which apply to surface water. Normally the water in the ground is under no external pressure except that due to the atmosphere, but the friction losses are always very large and vary slightly with the character of the strata. But it is possible that the water obtained from an Artesian well may be at a very considerable pressure and then the calculation of the yield is dependent upon different factors

1. Flow of Water at atmospheric pressure into an ordinary well.

From a brief consideration of the variety of conditions which prevail it will be evident that no simple formula can be evolved which accurately expresses the flow of ground water under any given circumstances. It is, of course, possible to obtain an approximate statement representing the flow in one district under certain given conditions, and many

such formulæ are available; but the only reliable method of obtaining accurate data regarding minimum flow is to make an actual pumping test during a period of dry weather. This may be carried out effectively for a small area, but it is neither feasible nor economical when attempted on a large scale. In such cases tests must be made at certain selected points and the yield of the area deduced from these results.

A well must always be sunk some distance below the ground water-level, in the first place to allow for depletion of ground water during dry weather and also to allow for the lowering of the general water-level in the neighbourhood of the well. After pumping is commenced the water-level in the well will fall until a point is reached at which the flow into the well equals the quantity pumped, when the water will remain at a constant level. An examination would then show that the surface of the water in the neighbourhood of the well had taken up the form of an inverted cone with its apex at the water-level in the well. The ideal surface of the cone will be in the form of a parabola, becoming steeper as it approaches the well. The extent of the cone and whether it is shallow or deep depends upon the character of the strata. The area inside which the ground water-level begins to fall is called *the circle of influence.*

Before pumping is commenced the water will be flowing at a very slow rate through the porous strata, with an inclination of surface or hydraulic gradient of perhaps 10 or 15 feet per mile. When pumping is started this head is not sufficient to supply the demand and the water-level around the well falls until sufficient head is obtained to overcome the greater friction due to an increased velocity. It follows, therefore, that the yield of the well may be increased by pumping at a greater rate and so lowering the water level, i.e. by increasing the hydraulic gradient.

A pumping test is usually made by pumping at such a rate as to maintain a constant water-level, providing the inflow is sufficiently large to allow continuous pumping. It would appear that the quantity pumped should be a reliable indication of the water available in the ground and the yield of the well. But this is not always so, for it is found that although the water level in the well may remain constant over a long period (perhaps for some months) the circle of

influence will gradually widen out and the yield will very slowly begin to decrease. This is most likely to occur in a strata with fair porosity and a flat surface gradient. It is therefore advisable whenever making a test to take observations, if possible, of the effect of pumping upon the ground water-level round the well, in addition to the water-level in the well itself.

When water can be obtained within a reasonable distance below ground level horizontal galleries may be driven from a shallow well at right angles to the natural direction of flow of the ground water and at the bed of the water-bearing strata. It is apparent that a very much larger proportion of the ground water will be intercepted in this way than by a single vertical well. It is not usually found to be economical to adopt this method for depths above 25 feet unless the ground at a greater depth is favourable for tunnelling.

The gallery is usually constructed in the form of a culvert with openings in the sides and bottom or top to admit the water. and it is usual to provide inspection chambers, or better still to allow for inspection of the entire length.

Such galleries act as storage reservoirs and are of the greatest value in any case where a porous and inclined water-bearing stratum rests upon an impervious stratum at the same inclination and at reasonable depth. Such conditions prevail and have been developed in the above manner at Munich in Germany.

This method of collecting water has not been largely employed in Great Britain, but many examples are to be found on the Continent and in America.

The same principle, however, has been employed in this country at a greater depth in the chalk with considerable success The yield of water from the chalk is largely dependent upon fissures, and as more of these can be intercepted the yield will correspondingly increase, so that in the Upper Chalk a heading will probably be very successful. It is also an important practical consideration, that chalk is a particularly easy strata for tunnelling. In the Lea Valley near London the conditions are entirely suitable and the yield of water from the strata has been very considerably increased by the construction of several miles of headings. But in denser chalk which is free from fissures a heading is of very little value.

Only a few miles from the Lea Valley, the character of the chalk changes and becomes denser and wells with headings in the Finchley district have been abandoned as total failures. A complete investigation should therefore be made, before any heading is attempted.

Other examples of headings are provided by the one connecting the wells supplying the fountains of Trafalgar Square to a well in Orchard Street, and also by a heading ¾ mile long at Otterbourne in Hampshire for the Southampton water supply.

2. Flow of Water into an Artesian Well.

In the case of artesian wells where the porous water-bearing strata is overlaid by impervious strata and the water enters the well under pressure there will, of course, be no change in water-level near the well, since the water will continue to exert pressure upon the impervious strata. But an examination would show that the water pressure decreased near the well and a curve of pressure would take a similar form to the water surface in the vicinity of an ordinary well. Such an investigation is only possible when the water-bearing strata is at a reasonable depth. The conditions governing the water surface in an ordinary well also apply to the curve of pressure in an artesian well; thus the pressure will decrease at a greater rate as the water-bearing strata is more impervious, causing greater frictional losses, and the circle of influence at the same time will be smaller.

General Principles governing the Yield of Wells.

In Chapter II it was shown that the different strata in the geological formation varied considerably in water-bearing properties. It is apparent that one of the primary considerations governing the yield is the water-capacity of the strata tapped by the well. But the yield is not necessarily *proportional* to the "capacity" of the rock, or the quantity of water it can contain when saturated. All rocks can permanently contain a certain amount of water called the "water of imbibition" which represents the natural moisture always present in the rock. In addition to this the rock is capable of absorbing a further quantity of water up to its point of saturation. The water which can be drawn off by

means of wells is represented by the difference between the quantity the rock can contain when saturated and the water of imbibition. Chalk will hold about 18 pints of water per cubic foot when saturated, but 10 pints of this is water of imbibition or natural moisture, so that the yield would be only about 8 pints per cubic foot. A rock only parts with the water of imbibition with great difficulty or by artificial means.

The capacity of a water-bearing strata is directly proportional to the saturation, but in inverse ratio to the "imbibition".

Again certain strata part with water with much greater ease than others. Thus a pure sand such as the Lower greensand formation easily gives up water, but the Upper greensand, which contains clayey particles, only transmits with difficulty since the crevices become choked up with clay. Sandstone parts with water readily by reason of cracks. Chalk formations, although possessing a strong affinity for water, usually part with it fairly easily on account of cracks and fissures. It has already been pointed out that the hydraulic gradient in the Middle and Lower chalk is steeper than in the Upper Chalk and this is due to the more fissured state of the Upper Chalk. Cracks, such as often occur in a limestone strata, may allow water to traverse an otherwise "dry" formation since they serve as underground pipes along which water may easily find a passage between two impervious strata.

Impermeability is really the condition which prevails when the saturation and imbibition of a rock are in equilibrium. Clay and granite are good examples representing this state.

It is sometimes found that a spring or the head of a stream moves up and down a valley at certain times of the year. This is due to variation in the ground water level, which rises perhaps some feet during a wet season, carrying the point of overflow at ground level hundreds of yards up the valley, and falls again after a dry season causing the spring to move down the valley again. An intermittent or movable spring such as this is called in some districts a "bourne" and in others a "lavant".

A well-known example is the Croydon Bourne, which flows intermittently down the Caterham Valley. In this case the

high ground South of Croydon receives a much greater rainfall than the low ground near to the town, so that the ground water-level is raised more quickly, after heavy rains, in the high level area than in the low level, resulting in a steeper gradient. The increased pressure due to this gradient would cause a larger underground flow were it not for the density of the chalk which offers considerable resistance to the flow. The water, therefore, chooses the easier path and finding its way through the more fissured chalk near the surface finally appears as a bourne. Other bournes would, no doubt, appear in this neighbourhood where conditions are generally favourable, except for the fact that in most places the chalk is overlaid by the Tertiary sands.

If considerable pumping is taking place along the course of the bourne, the flow may be less down stream than near the source owing to a local depletion of ground water which causes the water of the bourne to re-enter the ground to make good the deficiency.

When calculating the yield of a deep artesian well it may be necessary to make an allowance for friction losses in the well-tube. Usually such friction is negligible, but becomes appreciable when a large quantity of water is delivered from a group of deep borings and may seriously restrict the supply if an allowance is not made. Excessive friction followed by a decreased yield may also be caused by restricted openings in the well tube or obstructions in the tube itself.

In sandy strata trouble may be experienced by silt in the bottom, which reduces the flow and may also cause trouble with pumps. Usually it is quite easy to remove this silt by means of a sand-pump, but if the silt has collected around the outside of the tube it will be necessary to resort to a steam jet or compressed air An air-lift employed for raising water has the effect of keeping the bore-hole clear.

In practice it is impossible to utilize the whole of the percolation into a ground water source of supply, but the maximum yield may be obtained by sinking to the underlying impervious strata if practicable, and pumping at such a rate as to keep the water very low in the well, only leaving a minimum amount in the well to provide storage for pumping. A limit may also be placed upon the yield by the existence of neighbouring wells or streams in which the water-level

would be lowered by excessive pumping and would be quickly followed by expensive litigation and claims for compensation. Thus it is apparent that no attempt should be made to lower the water-level below that existing in neighbouring wells except under special conditions and with the permission of the other well-owners.

It has already been pointed out that the most reliable method of determining the available yield is to make an actual pumping test; but failing this, the results experienced in other wells in the district, or in wells in other districts where the conditions are similar, afford valuable indication of the possibility of success for a new well.

Some valuable information on ground water supplies has been obtained by Dr. D. Halton Thomson, M.A., Assoc.M.Inst.C.E., and published in a paper entitled "Hydrological Conditions in the Chalk at Compton, West Sussex", read before the Institution of Water Engineers in December, 1921, and the reader is referred to this for more detailed information.

From this paper it becomes apparent that the ground water storage has a very considerable effect upon the available yield of the chalk and if similar facilities for observation were available the same would no doubt be found to apply to other geological strata, although perhaps not to the same extent.

It was also found that when the ground water storage was eliminated, there was a close relation between the annual rainfall and the yield, but that the "loss" was nearly independent of the rainfall.

The results obtained by Dr. Halton Thomson are of particular value since the experiments for determining the saturation level, percolation, etc., were carried out on a large scale, not at a small experimental station which is liable to give misleading results. For instance, the material in a small-scale percolation gauge is not existing under the same conditions as in the natural ground and is unlikely to represent completely the variety of conditions which may occur in practice. It is also possible that the effect of evaporation extends to a greater depth than 3 feet during hot weather owing to capillary attraction. The normal percolation gauge which is 3 feet deep makes no allowance for this.

The methods adopted by Dr. Halton Thomson in making observations are both interesting and valuable, and also more reliable than many similar investigations, since accurate and continuous records of ground water-level and rainfall were available for a number of years past and practically no pumping was in progress in the area under investigation. Thus it was possible to determine the relations between rainfall, percolation, and yield with considerable accuracy.

Arrangement and Spacing of Wells.

The actual diameter of a well does not largely affect the yield, although, of course, in the case of a bore-hole the tube must be sufficiently large to allow the available yield to pass up it without excessive friction.

The advantage of a large well is that it possesses large storage capacity, which may be necessary in pumping operations, and plenty of room is available for the pumps. Also the possibility of clogging is reduced since the water enters slowly and no difficulty is likely to arise in keeping the well clear. On the other hand, the expense of construction is largely increased and rises rapidly as the depth increases. It is often found most economical to sink a well 20 feet or 30 feet in diameter to a certain depth to contain the pumps, and then to drive bore-holes down to increase the yield. As previously mentioned it is also feasible occasionally to drive galleries from the bottom of the well.

When a system of wells is under consideration the sizes should also be considered in relation to the spacing.

If two wells are too close together or too large, the total yield will not be double that of a single well owing to mutual interference; under such conditions neither the construction nor the pumping will be carried out as economically as might be.

The most economical spacing of wells is a matter which requires careful investigation for the particular system contemplated. It will depend chiefly upon the depth of the ground water level, the depth to which the wells are driven, and the character of the water-bearing strata. There should, of course, be a space between the circle of influence of any two wells, and notice should be taken of the extent to which the water is lowered by pumping. Thus it will be necessary to

decide whether it will be more economical to have a few wells spaced at considerable distances apart and a large amount of pumping, with increased head at each well, or, alternatively, to have more wells, spaced more closely, with a smaller volume of pumping at each and a smaller head.

Care should be taken that the size of the well is sufficient to reduce friction to a reasonable amount. For shallow wells it is usually best to keep frictional losses down to 2 or 3 feet even at the expense of a slightly larger well since the annual cost of pumping will be reduced. The friction will, of course, necessarily rise considerably above this amount as the depth increases.

The probable correct spacing for deep artesian wells can only be determined from an experimental boring or from other wells in the same or a similar district. Generally it is found more economical to have a greater spacing for deep wells than for shallow ones. Between 500 feet and 700 feet has often been found to be satisfactory for 6 to 8 in. diameter bore-holes. But the most economical pump and the type proposed to be used, together with the best size of bore-hole for the strata likely to be experienced, will also affect the final decision.

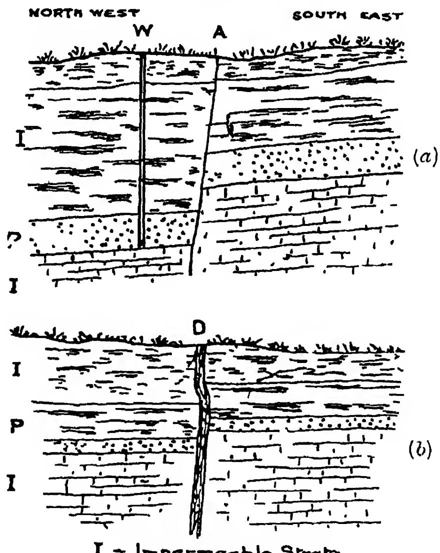
The only method of utilizing the total available yield from any water-bearing strata is to sink a series of wells and to pump to such an extent that the lowest possible water-level is maintained. This may be the base of the water-bearing strata or the level of ground water in the vicinity. By this means all ground water is induced to flow towards the wells and a negligible amount is allowed to escape.

There must always be some doubt regarding the success of a well until it is actually in operation. but the risk of failure may be considerably reduced by a close study of the district. In fact, with the mass of information now available regarding underground water in Great Britain an occasion of entire failure should be almost unknown. At the same time the yield may easily be over-estimated, and occasionally it is found to have been under-estimated. There are many possible causes of partial failure, but principally it is due to "faults" in the geological formation or to interference by other wells in the vicinity.

If the strata is displaced by a "fault" in the manner

shown in Fig. 8*a* the supply of water to the lower portion of the porous strata may be entirely cut off, since the impervious material forms an effective barrier. A spring may be formed at A if there is sufficient pressure, but it is apparent that a well sunk at W would almost certainly be a failure. It is quite possible that the existence of this fault might not be known if no similar work had been carried out in the neighbourhood, so that it would be very advisable to put down a small trial boring before incurring the greater expense of extensive works.

FIG. 8.



Faults.

A good example of this is provided by a fault which extends from south-west to north-east between Surbiton and Camberwell. The downthrow is on the north-west side so that the impervious London Clay is adjacent to the water-bearing sands (see section, Fig. 8*a*) and interrupts the natural flow of the water. The result is that the ground water in the neighbourhood of Richmond has been considerably

depleted by over-pumping owing to the curtailed area of supply. The water which would, naturally, flow into that area is, in fact, deflected by the fault in a north-easterly direction and reaches the Wandle Valley, where the yield, in consequence, is considerable and the water level is only a few feet below the surface. In many parts of this district the water did overflow at the surface and even considerable pumping has only lowered the level a few feet. Thus whereas the average water level of wells in Mitcham and Merton fell only 20 to 30 feet in as much as fifty years, the water level in a well at Mortlake dropped as much as 220 feet in about the same period and in a well at Richmond the level fell 50 feet in two years.

A similar effect to the fault may be produced by a " dyke " as at D, Fig. 8*b*.

A " dyke " is a fissure or vein extending regularly in a straight line or plane, often for a considerable distance, and usually filled with igneous rocks. Evidently if the dyke is composed of impervious material it will effectively interrupt the flow of water.

If, on the other hand, the dyke is composed of porous material it may form a valuable site in itself for a well, since it will often act as a storage reservoir unless it extends to another porous strata in such a manner as to allow the water to flow away to a lower level.

The extent of outcrop of the porous strata also assists in determining the success of the well. An otherwise ideal water-bearing strata may be rendered almost useless if inclined at a steep angle and having only a small area exposed at ground level.

From what has been said previously it will be apparent that the pumping in existing wells may seriously affect the success of a new well, or *vice versa* ; so that every possible investigation should be made before a new well is sunk in the neighbourhood of old ones.

CHAPTER IV.

THE CONSTRUCTION OF WELLS.

THE practice of well-digging is rapidly falling into disuse owing to the great danger of pollution due to the infiltration of impurities from the surface. The well can, of course, be lined with brickwork, and in practice the looseness of the strata near the surface usually necessitates this for some depth, but at the same time it is difficult to insure that the lining is impermeable. Again, the lining is usually omitted through strata of hard chalk or rock, and small fissures may allow polluted water to enter the well. Wells constructed in this manner may be found in Hertfordshire and elsewhere where a gravelly surface soil overlies the chalk.

So that it becomes apparent that a lining, or technically, steining should be provided for the whole depth of the well.

The mere excavation of a well requires but little skill, the plumb-bob and a rod cut to the diameter of the well being sufficient to ensure accuracy; but at times it is a matter of great labour necessitating blasting in hard rock.

Buckets, a windlass, and ropes are required to remove the products of the excavation. Where the well is sunk through stiff clay, as, for instance, that in the London basin, steining of half-brick thick, or four inches and a half, is required for small wells, and of 9 inch work for wells of large diameter.

It is important that only the best material should be used for the steining. Bricks should not have more than 5 per cent absorption and preferably should be set in cement mortar, the cement having a fairly quick initial set. If part of the work is laid dry, in stiff or rocky strata, the taper joints in the brickwork should be filled up with a stiff clay to fill up any aperture at the back of the steining. It is important that this space should be solidly filled up and it may be found necessary to put in concrete mixed in the proportions of about 10 of aggregate to 1 of cement.

Loose, wet sand, or loam, test the skill of the well-diggers, and it is in such cases that most careful puddling becomes

necessary behind the brickwork; it is safer to adopt steel lining in such strata. In a greasy strata such as the Mottled Clay care must be taken that the upper steining does not slip while the work is being executed. Again in passing through land-springs, they must be carefully walled out, by executing the brickwork entirely in cement—an operation which can only be accomplished when the quantity of water entering from the spring is limited: where the rush is considerable, as in sinking through main sand-springs of the plastic clay formation, the water must be dammed out, by substituting for brickwork, cylinders of iron, which may be either cast or wrought: the latter are the more modern, and have been applied in some large wells; the former are the more convenient for handling, being bolted together in segments, or in divisions. When the sinking of such cylinders is necessary, digging will most probably be precluded altogether, and boring alone will be admissible, the cylinders sinking as the sand is bored out: when they have been sunk to a sufficient depth in the solid clay beneath, digging and steining may go on as before. If it be determined to bore, near London, into the chalk, the boring should commence before the sand-spring is entered, the expense of large cylinders being thereby saved, as their place would be taken by the small bore pipe; and as the water from the chalk will generally rise higher than the level of the sand-spring itself, no advantage is gained commensurate with the increased outlay by sinking large cylinders. The position of the sand-spring can be determined by boring in advance of the well itself, while the latter is being sunk through the plastic clay; by driving a bore-hole very small, and thus feeling the way, no danger of a surprise may then be anticipated.

Steining is executed in a variety of ways, as regards its manner of application, its thickness, and its bond. The bricks used should be hard, square, and well burnt; if the cost will allow, malm paviours should be used, and if stocks are employed they should be the very best. As the work is for the most part laid dry, unless the bricks run of one uniform thickness, a great waste of time and trouble will unnecessarily take place during the steining; again, as the bricks are laid so as only to touch each other at the edges.

a soft crumbling brick would manifestly be useless. The old method of executing the steining was by building on a curb of wood shod with iron. The earth being removed from the bottom, the curb and its superstructure sunk down; the brickwork was then added from the top, and this method of proceeding continued till the curb would sink no longer, owing to the swelling of the ground; a new curb and new excavation smaller than the last were then begun.

This method is now seldom used except in peculiar circumstances, all bricks being added under the executed steining, the latter being kept from slipping by artificial means when the natural swelling of the ground is insufficient; this circumstance is unlikely to take place when the bricks are worked close to the sides of the excavation, in clayey soils especially; generally the friction acting to prevent slipping is enormous. The steining is usually executed partly in dry and partly in cemented work, the latter occurring as rings laid at intervals between the

FIG. 9.

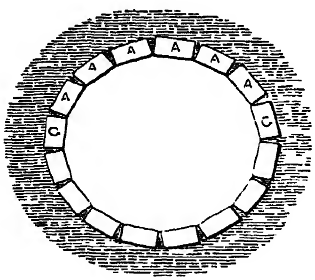
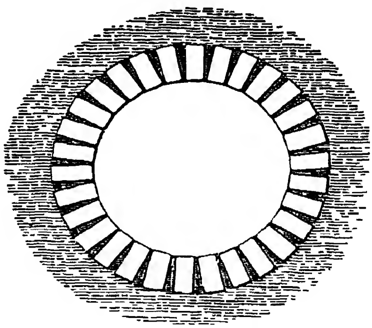


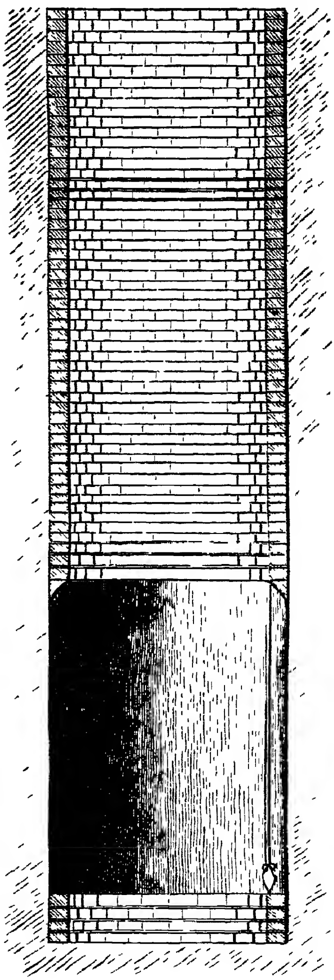
FIG 10.



portions of the work laid dry; these are regulated by the nature of the ground, in London clay, the intervals generally vary from 5 to 12 feet, though sometimes the work requires to be laid for some distance entirely in cement. The rings are usually three courses thick, averaging about 9 inches in height; the bricks are laid flat, as in Fig. 9, the courses alternately breaking joint: it is often desirable to insert cement or small wedges in the open spaces at the back

of the touching edges of the bricks. The thickness of the steining itself depends on the diameter of the well and the nature of the ground to be passed through; some use 9 in. work laid dry, and radiating as in Fig. 10; this is evidently not so strong as $4\frac{1}{2}$ in. work laid in cement, or even backed with the same in the manner described above; therefore, if 9 in. work be ever used it should be laid in cement, as being in a situation where $4\frac{1}{2}$ in. work in cement will not suffice. In commencing an excavation from one cement ring to another, the hole is dug as far as is safe or practicable; the nature of the ground will determine this; a line is then plumbed from the brickwork above, which will give the position of the face of the brickwork in the lower ring (see Fig. 11, which represents a section of the steining of a well); the cement is usually gauged with half sand, as in works above ground. Too quick setting a cement is not desirable, as it partially sets in being conveyed down the well to the workmen, but any good Portland Cement passing the British Standard Specification Tests may be used. In many cases, even where the work does not absolutely require it, the steining is done entirely in cement, a practice which makes excellent work, but which is attended with a further disadvantage than the extra cost of

FIG. 11.



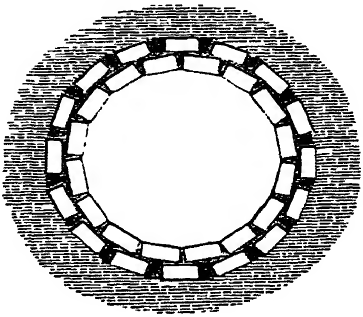
execution, since it occasions much trouble and loss of time in fixing either the permanent or temporary pumps.

In sandy soils, should the well not be deep, the old plan of working on a curb may be adopted, but in deep wells that is inadmissible; here the steining should be set entirely in cement, and, to prevent slipping, the work should be laid in quarters, care being taken to well hang up the steining on the completion of the work by the insertion of an iron curb, secured in its place by tie-rods, which are carried up the shaft and bolted to cross timbers or another curb fixed into the brickwork. In some wells that have been executed in sandy soil, cast-iron curbs have been inserted at intervals, each curb slung to the one above it by tie-rods; the gravel or sand can then be excavated under the curb as the clay can under the brick-work rings set in cement; the curbs, in fact, bearing the same relation to the cemented brickwork in the case of sandy soils as the cemented rings do to the dry brickwork in clayey ground. The method of bond or laying the bricks remains to be considered: Fig. 9 shows this. The bricks, though they do not touch exactly at the edges, for practically that is impossible, yet are set in only a trifle, and the harder the description of brick the more nearly may the edges abut; the swelling of the ground will soon fill up the spaces at the back of the edges when the bricks are laid dry: this method induces fewer joints than if the work were laid as in the manner usually adopted for half-brick arches above ground, and for other reasons is more fit to this purpose. The ground behind them prevents any displacement of the bricks, for, the tendency of the pressure being to twist them, a compression of the ground must necessarily take place before movement can occur; thus the bricks, A, A, A, etc., in the figure, before they can be moved nearer to the centre of the well or alter their position, must force outwards one or other of their two neighbours, G, G; these cannot evidently be so moved without compressing the solid ground behind: here, again, we see the advantage of working as close as possible to such ground, and if at any time, owing to a stone or otherwise, the excavation be not perfectly round, care should be taken to puddle with solid

clay behind the steining to prevent displacement, and thus form a sufficient abutment.

The work when 9 inches thick is laid either radiating, as in Fig. 10, or in separate $4\frac{1}{2}$ in. rings, Fig. 12; the latter plan is usually adopted, and may be considered the best, for the following reason, it being understood that the work in both cases is laid in cement. Considering the strength as that of a compound of bricks and cement as in Fig. 12, fracture of the cement must take place before any failure. while in Fig. 10 a slipping of the bricks away from the cement might occur; and again, in executing the work it might be considered advisable—indeed, it generally is—to execute the back steining first, for a certain distance, and afterwards to complete the inner. Even work, not wavy, but strictly vertical, constitutes good steining, and looking upwards from the bottom of a well will at once detect if the work be true or not, the eye in such case being placed close to the steining.

FIG. 12.



Well-diggers, after attaining a certain depth, find the confined air very unpleasant and noxious. The carbonic acid from the breath, being specifically heavier than common air, soon stagnates at the bottom of the excavation: lime-water is sometimes recommended, as this will absorb the carbonic acid; it is, however, an awkward and unworkmanlike expedient An air pump or fan may be used in such cases, and the air conveyed down the well in pipes; quite small ones answer the purpose very well; they are about 2 inches in diameter. The depth of hole at which an artificial supply of air is desirable will depend on the diameter of the well and the position of the aperture. If it be open to the air, with no temporary shed or other erection over it, a supply may not be required, with a 4 ft. excavation, till about 130 feet from the surface. In this question, however, the extreme limits should not be sought for, as the sooner a plentiful supply is given the better, the

workmen getting on more comfortably to themselves, and also much more rapidly.

In the construction of iron steining the wrought-iron cylinders are riveted with internal ribs of angle or T-iron, so as to be flush on the outside, the rivets being countersunk to attain this end; lowering rings are also riveted inside them, for convenience in fixing. Cast-iron cylinders being much thicker, and therefore heavier, will sink into the hole with less driving; they are cast in about 5 ft. lengths, and are joined together with bolts and internal flanges, In sinking cylinders, their vertical position must be insured by letting them travel or slide between four battens, fixed as guides, and secured to the brickwork. When iron cylinders are used it is generally necessary to support the lower part of the brickwork, as the sand and water will give it no support, an elm or iron curb is therefore used for the purpose, which is attached by iron rods to wood beams let across the well, or iron curbs inserted some distance up the shaft. The space between the cylinders and brickwork should also be well concreted, so as to shut out the water, which would otherwise rise up from the sand. To prevent land-springs or drains from percolating into a well it is advisable to execute the first ten or twelve feet from the surface in 9 in. work, the same being well puddled behind. When the land-springs are very strong they must be shut out by the use of cylinders, as previously described.

CHAPTER V.

BORING.

THOUGH boring practically requires skill and care, yet in principle it is extremely simple. The operation consists, as its name would imply, in working a hole, in this case made in the crust of the earth, of a diameter varying according to circumstances, and in a vertical direction generally; not so always, however, for certain requirements may demand that it should be oblique. Many systems have been and now are practised in carrying on this kind of work; and though only two or three are in general use, it is instructive to examine certain modifications together with some of the less common methods.

The simplest is the original Chinese Rope Boring System, which is of great antiquity; here all rods connected to the boring-tool in the ordinary plan are dispensed with, the borer being suspended by a rope, which, when the tool is worked vertically up and down, imparts by its torsion a sufficient circular motion to the tool. In this case the tool and the rope are surrounded by an iron cylinder, and the products of the excavation become collected in the circular space between the tool and the cylinder, by which means they may be brought up to the surface of the ground. With so simple a machine, different tools, of course, being used for various strata, it may be asked, why has this plan not superseded all others? Where simplicity can be gained without corresponding disadvantage, it is well to employ it; but where a manifest inferiority exists, to choose simplicity in opposition to complexity, for its own sake alone, is absurd. To this plan one serious drawback occurs, which is, that the bore-hole is apt to become crooked, so that some difficulty is at times experienced in sinking the pipes necessary for protecting the hole.

Improved systems of boring with the aid of a rope are, however, in use, and possess many advantages over systems in which rods are employed.

Boring systems are divided into two main classes, viz.:

Percussion Boring, by which a hole is forced into the ground by reducing the rock to a powder; and Rotary Boring, by which a hole is drilled and a solid core obtained.

Percussion Boring may be carried out in the form of a Driven Tube Well or a Bored Tube Well. In the latter case either ropes or rods may be used, and advantage may be taken of a system of Hydraulic Washing (see p. 67).

Rotary Boring systems differ principally in the form of cutting tool employed. The diamond system was at one time exclusively employed, but a Rotary Shot system is now largely used, particularly in oil borings.

Percussion Systems.

The *Driven Tube* is the simplest form of bore-hole; it is only rarely employed, and never for diameters above 6 inches or depths greater than 60 or 70 feet.

A tube of the required diameter and having a solid pointed shoe at one end is driven down vertically. Successive lengths of tube are screwed together with water-tight joints as driving proceeds until the water is reached. Perforations in the bottom tube allow the water to enter and rise up the remaining tubes to a point from which it may conveniently be pumped by means of a hand-pump. Such wells are usually only attempted when it is known that the water will rise to a sufficient height to be raised by a hand pump and short length of suction, although, if desired, a foot-valve and lift pump may be fitted as described on p. 72.

Bored Tube Wells.—The most common system of well-boring is to work a vertical hole in the ground, of the required diameter, remove the comminuted material, and then line the bore-hole with tubes either for the whole depth or through the less solid strata, each operation being carried out only for a few feet at a time.

The boring tool, which differs according to the nature of the work to be done, is attached to steel or wooden rods in lengths of from 3 to 20 feet, and a vertical reciprocating motion is given to the borer, thus breaking up the material at the bottom of the bore-hole and penetrating the strata. A circular motion is also given to the borer by a workman at the surface in order to ensure that the tool does not strike

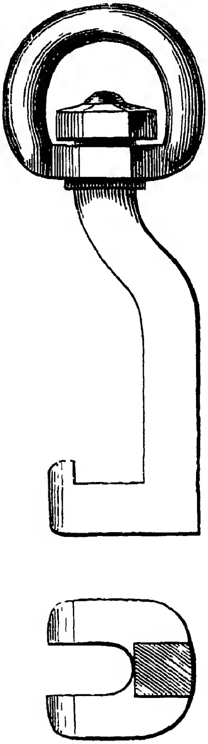
the same point at each stroke. It is evident that by this plan a great loss of time is entailed, for the tool must be drawn to the boring-stage from time to time and the hole cleared of the débris, and to effect this the rods must be unscrewed. This screwing and unscrewing, pulling up and letting down, is an operation entailing a great loss of time, which it is important to reduce to a minimum.

Certain preparations are necessary before commencing the boring itself. Sometimes a well is dug before the boring is started, and if this well is greater than about 5 feet in diameter some gear above ground may be dispensed with. If the well is smaller than this, it is difficult to obtain sufficient room to work in. Some of the advantages of working in a well are as follows: first, there will be a great saving of temporary work above ground, for the stage the workmen bore from must, if above ground, be elevated some distance from the surface—20 feet at least—or great waste of time will take place in screwing and unscrewing the rods, etc.; secondly, less weight of rods will be on the windlass, for, if the boring takes place from a point in the well, the rods need only be suspended by ropes from the windlass to the stage in the well from which the boring takes place; and there will be an economy in time in screwing and unscrewing the rods, as they may be drawn up without detaching them from each other, in lengths equal to the distance of the windlass to the boring stage nearly. To reap the same advantage when boring from the surface, a high pair of shears or a triangle is necessary, which, of course, adds to the expense and trouble.

Supposing it was decided that boring should be carried on in the well, care should be taken in fixing the position for the stage or floor from which the work is done; this should be as low as practicable, as may be supposed from what has been said before; but at the same time the stage should be a sufficient distance above the level in the well to which the water will rise. This is a consideration which can be ascertained only by experience and a knowledge of the spring-water level of the district. The stage consists of a stout plank floor resting on strong putlogs. The flooring is well braced together by planks nailed transversely across the same. In the centre of this floor is a square hole, a

little larger than the boring-rods, which therefore can pass through it, but not large enough to pass a small hook apparatus, represented in Fig. 13, which, having the power of holding the rods suspended while they are screwed and unscrewed, will prevent their falling through the stage. From the bottom of the well to above where the water will rise, say to nearly under the boring stage, wooden trunks, strongly but temporarily secured, are fixed as guides for the boring tools, permanent pipes, etc. These trunks may be made square, and are fitted by sockets one into the other. Sometimes temporary iron pipes are used instead of these wooden trunks.

FIG. 13.



If it is impossible to commence the boring from the bottom of the well more elaborate boring-rig is required at ground level for operating the tools.

For moderate depths sheerlegs, at least 40 feet long, may be used, the rods and tools being slung from a pulley block fixed at the head of the sheerlegs.

For deeper work a derrick or sheer-frame should be used, and the rods and tools operated either by a windlass or steam power.

Boring-rigs are constructed either in wood or wrought iron tubes, with head pulley and block over which a rope is passed to support the boring rods and tools. One end of the rope passes to the windlass in hand-power rigs, or to the winch or winding drum in a steam driven plant, the operation of which is described later.

The boring-rods are usually of mild steel, square in section, and varying from 1 inch to 3 inches thick. For a bore-hole 3 or 4 inches diameter up to 150 feet deep, 1 inch rods may be used, and, of course, as the depth and size of bore-hole increases larger rods will be required. The rods are made in varying lengths from 3 to 20 feet, to make up the total length

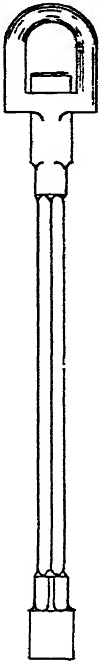
required at any time. The rods are jointed by a male screw with an enlarged boss at the base screwing into the socket of the next rod so that the boss butts tightly up against the head of the socket.

The rods should be examined, particularly at the joints, each time they are raised and any defective ones replaced, for very considerable delay inevitably follows a broken rod.

FIG. 14.

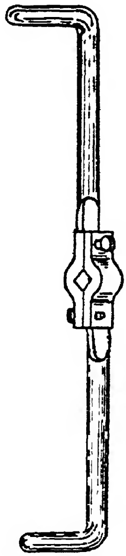
Boring Rod

FIG. 15.



Swivel Rod.

FIG. 16.



Rod Tiller

The rope from which the rods are suspended is passed over a pulley at the top of a spring hook which is attached to the eye of a swivel-rod. At the other end of the swivel-rod is a screwed socket into which the first rod is fitted. A circular motion may be given to the rods during boring by means of a rod-tiller which is clamped to the rods at a convenient height above the staging and operated by manual labour.

Additional rods are screwed on, as the boring progresses, with the aid of a lifting-dog to hold the line of rods up while each section or length is removed. The same procedure is adopted in withdrawing the rods.

In borings of small depth and diameter the rotary and percussive motions are produced by manual labour; for a considerable depth, however, steam power is generally employed on account of the weight of the rods. Horse-power has been employed on many occasions; in sinking the well at Grenelle, completed in 1841, M. Mulot used the horse-mill, but steam is almost universally used now.

The rotary motion is usually communicated by means of the rod-tiller, as described above; and in tolerably yielding materials such as clay, sand, soft chalk, etc., no other motion is required to secure the descent of the boring tool; but in harder material it is necessary to comminute the rock before the tool can make any progress. The simplest method of doing this is to suspend the rods by a rope coiled two or three times round the barrel of a windlass, and adjusting the rope in such a manner that if a workman hold one end of the coil tight the friction will be sufficient to raise the rods when the windlass is set in motion. Should the end of the rope the workman holds now be slackened, the coil becomes loose, and the rods descend with a force proportionate to their own weight and the distance through which they have travelled. A regular percussive action is therefore gained by keeping the windlass constantly in motion in one direction, the attending workman alternately allowing the rods to be drawn up a certain distance and then, by relaxing his hold, to fall.

From this description of the manner of communicating the different movements to the rods it must be evident that their weight is a very important consideration and that in order to resist the efforts of torsion and percussion they must be made of dimensions proportionate to the depth of the bore. Thus for depths up to 150 feet the 1 inch rod probably used will weigh about 3⅓ lb. per foot lineal. A bore-hole between 600 and 700 feet deep and 6 or 8 inches diameter will necessitate the use of rods at least 1½ in. square, weighing about 10 lb. per foot lineal; while for still greater depths rods weighing as much as 15 lb. per foot lineal may be necessary, although it is usually possible to

employ lighter rods for part of the depth. The weight thus increases rapidly with the depth; and when the latter is considerable, inasmuch as the upper parts bear on the working end, the danger of fracture also increases.

At very great depths not only does the weight of the rods become an item of serious consequence, but when the percussive motion is given by the rods they vibrate with great force, and striking against the sides of the bore, they are likely to detach portions of the rock, which would, in that case, fall upon the top of the tool. This danger has sometimes been obviated by using lighter but larger rods; indeed, as the bore-hole is usually filled with water, and therefore the rods lose a portion of their weight, it is advantageous to increase the volume, even if the weight remain the same. Years ago M. Degousée effected the desired object by using wooden rods surrounded by iron bands and with iron screwed heads (see Fig. 17); or by using tubular wrought-iron rods of the same weight per foot lineal as the solid rods, but which, owing to their displacement of water, did not act so injuriously upon the lower portions, while at the same time their volume rendered them less liable to vibration. The wrought iron tubes present the advantage over wooden rods that they are better able to resist the effect of torsion; but the latter, on the contrary, are lighter.

FIG. 17.

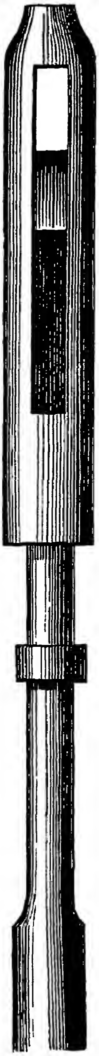
Wooden rod, bound with iron.

Beyond a certain depth it is dangerous to exercise a percussive action of such power as to expose the lower rods to be broken. In early borings many accidents occurred from the neglect of this consideration and perhaps the well of Grenelle furnished a greater number of illustrations of the necessity for the abstract theoretical calculations of the weight and description of the rods to be employed, than any well ever executed; it was marked by a continued series of accidents from this cause.

However, mild steel rods as above described may be, and now usually are, employed with safety up to 1,000 feet. Above that depth special precautions are necessary and the method usually adopted is to employ a form of sliding joint

on one of the rods near the bottom of the bore, based upon the invention of Œuyenhausen, in order to ensure the safety of the rods.

FIG. 18.



Œuyenhausen's slide-joint.

Œuyenhausen's joint consisted of a special rod divided into two portions; the upper one being counterbalanced by a weight suspended to a lever, and the lower one only allowed to act by percussion, the weight of the latter rarely exceeding from 12 to 16 cwt. Between these portions the slide-joint is introduced. It consists of two parts (see Fig. 18) able to slide upon one another for a distance of about one foot, and so arranged that during the descent one becomes detached from the other. The upper part is balanced by the counter-weight. When the boring-tool is allowed to descend after it has been raised for the purpose of getting the blow, it will strike the bottom simply with a weight equal to that of the lower portion, and the upper portion will descend gently through the distance of 1 foot until it rests upon the collar. Certain adaptations of this joint in the form of jar-bars and elaborate sliding joints are now used, to which reference is made later. The simple jar-bar, so arranged that the weight of the rods above it is not communicated to the boring tools, should always be used at 1,000 feet or over.

As the boring tool, in all these operations, is the acting part, its form varies according to the object proposed to be attained and the resistance of the ground to be traversed; the first condition being that it correspond with the diameter of the bore. The end of each tool carries a male screw joint for connecting to the next rod above. The boring tools may be divided into four classes, according to the object they are intended to effect: (1) tools for cutting or comminuting rocks by percussion (see Figs. 19–21); (2) tools for extracting soft or disintegrated materials (see Figs. 22, 23); (3) tools for

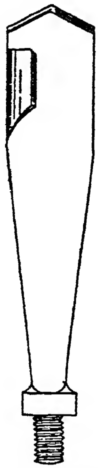
cleansing and enlarging, or equalizing the bore-hole (Fig. 24); (4) tools for extracting any broken rods, or for accidental works, or for raising or lowering the tubes (see Figs. 25–27).

The tools for percussion consist of a large number of chisels designed to deal with every conceivable form of strata likely to be encountered. In hard rocks, such as the oolites, a plain chisel with a diameter equal to the hole to be bored, and with a cutting edge, is sufficient. The shape

FIG. 19.

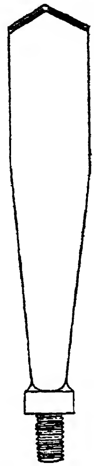
Flat V-Chisel

FIG. 20.



Tee V-Chisel.

FIG. 21.



Worm Auger.

represented in Figs. 19 and 20 is adapted to harder rocks such as the sandstones, because it divides the action. The worm auger, Fig. 21, is adapted for softer rocks and gravels.

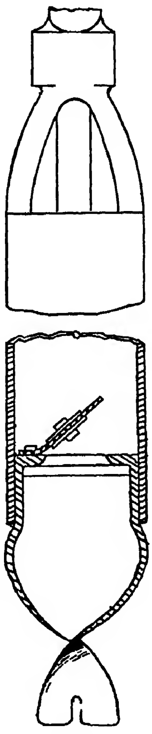
The augers are usually made upon the same principle as wood augers; that is to say, they consist of (1) a point which cuts the rock by its rotary motion; (2) a species of tongue, or occasionally of a clack, to support the loosened materials; and (3) the body of the auger, which contains these materials, at the same time that it serves to enlarge the hole (Fig. 22). It must be evident that these augers can only be used in soft ground, for they would not exercise any action upon hard rocks. Their forms differ according

to the nature of the strata traversed, being open and cylindrical, in clayey or calcareous lands possessing a certain degree of cohesion. They are closed, and sometimes conical, in running sands; and in this case it is also necessary occasionally to use closed augers with clacks, or a ball valve

FIG. 22.

Auger.

FIG. 23.



Worm Nose Shell.

FIG. 24.

Spring Rimer.

to prevent the accumulated matters from falling back into the bore (see Fig. 23).

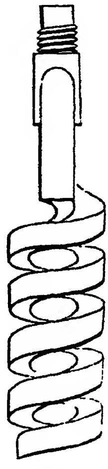
The vertical position of the rods is insured by attaching to them four guides fitting closely into the bore-hole, yet allowing the free action of the tools themselves.

The tools used for enlarging a hole may consist either of the chisels (Figs. 19, 20) already described. or of augers or the spring rimer (Fig. 24). M. Degousée used a very simple tool for the purpose of equalizing the dimensions of a bore, which consisted of two iron plates, from 5 to 7 feet apart, between which square bars with cutting edges were inserted vertically. These bars, if made to turn in the hole, would, of course, act upon the sides for their whole height.

FIG. 25.

Crow's Foot.

FIG. 26.



Spiral Worm

FIG. 27.

Bell Box.

Tools for recovering broken rods.

The tools for the purpose of recovering any broken rods consist of three principal descriptions: (1) the crow's foot (Fig. 25), designed to grip the rod below the male screw; (2) the spiral-worm (Fig. 26), used to withdraw portions of rods; (3) the bell-box (see Fig. 27), designed for use when the top joint is left on.

Should these means fail the only courses open usually are either to attempt to thrust the rod aside into the bore or in extreme cases it may be necessary to abandon the boring. In the case of a broken tool or portion of tool it is sometimes best to break it up and remove the bits with the other débris.

Chisels are usually made of mild steel with a specially

hard cutting edge and need constant attention. If the boring is to be maintained straight and true, they should be replaced immediately any signs of wear take place. In the softer strata boring may be continued some feet before appreciable wear takes place, but in hard rock the tool may be blunt after 1 or 2 inches.

It must not be understood that the above description comprehends every tool used by well-borers. Each contractor, in fact, has his own system, and the nature of the ground to be operated upon varies so much in one locality from what it is in another, that every case requires to be treated, as it were, upon its own merits.

The permanent pipe-lining to the bore-hole in the soft strata should closely follow the boring. Thus having, for instance, bored through the mottled clay, the sooner the pipes follow the better, as the sand underneath is liable to blow up into the bore-hole; in fact, the clay itself may fall when not dense and stiff and to a certain extent choke up the hole.

The lining tubes commonly used are made of mild steel, and are jointed by means of a male and female screwed joint with oil and red lead. There should be a socket at one end to strengthen the joint. The tubes should be almost flush inside and out when connected, and butt closely against each other, leaving a perfectly smooth surface on the inside. It is important that the joints should be air and water-tight in order to ensure the exclusion of all water except that actually intended to be admitted, or the well is liable to pollution from surface waters. The first pipe to be driven is fitted with a steel shoe which clears a passage for the tubes and allows them to fall easily into position.

As soon as it is thought advisable to line the bore-hole it is necessary to scrape and enlarge it slightly with the rimer in order to provide an easy passage for the tubes. The first tube with the steel shoe on the lower end is then hoisted on the tackle above the bore-hole and lowered into position. It is prevented from falling by means of pipe clamps, while a second tube is screwed into the socket of the first. The two are then allowed to drop into the hole. So successive lengths are added until the bottom of the well is reached, when boring should again proceed inside the lining tube until

sufficient depth is attained to add another length of tube. Until a considerable depth is reached no great difficulty should be found in lowering the tubes; if they are liable to stick at any time a few turns will usually free any slight obstacle which is holding them up.

As the depth increases it may be necessary to drive the tubes into position. A driving flange must then be fixed to the top of the tube, and driving is carried on with the aid of a "monkey" weighing from 500 lb. to 800 lb. for light work and 1,600 lb. for heavier work.

Driving is carried on with the same plant as used for boring with either manual power for shallow bore-holes or steam power for greater depths.

Sometimes the friction of a soft stratum on the sides of the lining tubes will be so great as to prevent driving more than about 100 feet without damage to the tubes. It is important that these soft strata should be foreseen, for in such a case it is necessary to start the bore-hole at a greater diameter than is actually required and line it as far as possible with large size tubes. The boring then proceeds at a smaller diameter and is lined with smaller tubes, which fit inside those originally driven. Thus the diameter of the hole is successively reduced as the conditions demand it. All the tubes should extend right up to ground level.

For withdrawing tubes when necessary a form of expanding tool may be used to grip the tubes so that they may be withdrawn with the aid of a hydraulic-jack. Alternatively, hooks attached to ropes may be lowered into the tubes and engaged on the rim of the bottom tube, when the whole line may be lifted up. It is only on rare occasions that the necessity of withdrawing tubes arises, and should only be attempted when absolutely necessary.

The tools and plant already described represent the usual practice in sinking bore-holes of a comparatively small diameter; for larger and deeper wells different tools are necessary and mechanical power becomes essential.

It has been proved that the yield of a bore-hole increases with its diameter, so that it is always advisable to provide for a larger bore than is absolutely required, especially if there is any possibility of much reduction in size as the well is sunk. Large tools also may be made upon rather different

principles so that they are more reliable and require less attention than do the smaller tools.

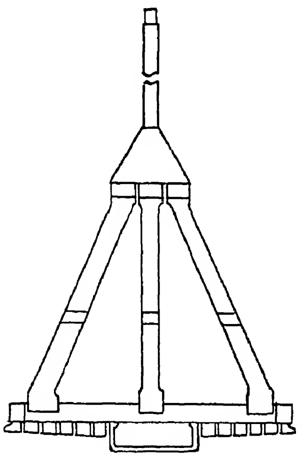
Difficulty in lining a bored well of large diameter has been experienced on many occasions, but the precautions usually adopted now are sufficient to ensure that the tubbing is strong enough to withstand all pressure which is likely to be experienced.

For sinking a well of large diameter on the percussive system the tool employed for comminution is the trepan (Fig. 28). This tool was first developed by M. Kind, and used in sinking a well 8 ft. 4 in. in diameter at Passy (see p. 103). The system of Kind was modified by Chaudron and later similar principles were employed by Dru with certain modifications, so that the methods of deep-boring employing a trepan are known under the names of the Kind-Chaudron and the Dru deep-boring systems. In both systems rods are used to support the tools.

Kind-Chaudron System.

The Kind-Chaudron trepan consisted of a solid wrought-iron frame with a cutting face varying in different tools from about 4 ft. 6 in. to about 14 ft. across, and weighing from 8 to 16 tons. The cutting teeth were made of the hardest steel, chisel pointed, each about 6 in. across the flat, fitting tightly into the base of the trepan. Above the cutting face, guides were fixed to keep the tool perpendicular, and these sometimes had cutting teeth fixed at the ends to trim the sides of the well.

FIG. 28.



Trepan

It will be quite apparent that if a tool such as this were allowed to fall through a height of 2 or 3 feet directly connected to the rods the vibration would very quickly shatter them. To overcome this an automatic sliding joint was introduced above the trepan which disengaged the tool from the rods prior to the concussion. Various types of the sliding joint were used by

Kind based upon Œuyenhausen's invention, in which the lower part of the joint (with the trepan) was released by the reaction of the water in which the tool would be working. If water was absent this type of joint was useless.

At the head of the well the rods were connected to a stout wooden horizontal beam by a chain, and the other end of the beam was connected, also by a chain, to the piston rod of a steam engine with a vertical cylinder. When steam was admitted above the piston, this end of the beam was depressed, thus raising the opposite end together with the rods and tool. By opening the exhaust valve the pressure above the piston was removed and the tool allowed to fall.

The valves were operated by hand, and the length of stroke (2 to 3 feet) together with the rate (usually about twenty strokes per minute) could be varied at will.

Special balancing arrangements were provided, and a subsidiary engine and plant were available for bringing débris to the surface or for raising and lowering tools and rods.

In operating this system the bore-hole is started with the small trepan and enlarged afterwards, but the smaller hole should always be maintained some distance in advance of the full diameter well, in order to keep a clean working face for the large trepan. The cutting face of the trepan slopes towards the centre so that an inclined face is obtained at the bottom of the bore, thus assisting the broken material to fall into the small hole. If some arrangement such as this is not made, after a comparatively short period of cutting débris will collect at the bottom of the bore and will merely be ground into powder, so that the effectiveness of the tools is lost and progress much retarded.

After a period of boring depending on the strata the trepan is withdrawn and a shell or ball-clack is lowered to collect the débris.

The maximum rate of boring is rarely more than 3 ft. per day under most favourable circumstances, and in a hard strata may be only a few inches per day.

The lining of the well usually consists of cast-iron cylinders with internal flanges, bolted together and slung down into the well so that a space is left between the outside of the tubbing and the face of the bore: this space is finally grouted up to strengthen the sides and make the well impermeable.

Dru Deep-boring System.

In the Dru deep-boring system the principle of operation was the same as that adopted by the Kind-Chaudron process, but differed in detail, principally in the design of tools. The design of the chisel, either as a single unit or as the tooth of a trepan, is most important and a considerable saving in time is ensured if the chisel is suitably designed for the work it is called upon to do and is so arranged that it may be easily removed and repaired when necessary.

The trepan employed by Dru was similar to the Kind-Chaudron trepan, but the chisels were fewer in number and wider, and were bolted to the base of the trepan to facilitate removal. In the small trepan there were only two chisels, and in the large four chisels were normally used, the cutting edge of the two centre ones being a little lower than the outer ones, thus assisting in guiding the trepan and maintaining a vertical bore.

The sliding joint used by Kind was limited in its use owing to the necessity for the presence of water to ensure its effective action. Two forms of sliding joint were adopted by Dru, each designed to allow a free fall for the trepan under its own weight alone, disconnected from the rods.

In the first type the lower member of the joint, with the trepan attached, was suspended from the upper portion by a hook arrangement. When the end of the travel was reached on the upward stroke the motion of the rods was suddenly arrested and the reaction was sufficent to release the hook in the sliding joint and allow the trepan to fall under its own weight. The rods and upper member of the sliding joint then descended on the down stroke, re-engaged the hook of the lower member of the joint, and the cycle was repeated.

This joint was found to be unsatisfactory for large size tools, as the force of reaction necessary to release the trepan caused excessive vibration on the rods and headgear, so that a second form was evolved in which the hook was released at a fixed distance from the end of the down stroke by the action of a pawl actuated by a disengaging rod which struck the bottom of the bore in advance of the trepan, and so disengaged the hook and allowed the trepan to fall. The upper member of the sliding joint then descended slowly with the

rods, re-engaged the hook and lifted the trepan on the up-stroke.

The remainder of the tools and plant employed together with the method of working are similar to those in the Kind-Chaudron system. It is necessary that the trepan shall be rotated slightly between each impact in order to preserve a uniform surface at the bottom of the bore-hole. This is usually done by hand while the rods are on the upward stroke, and should be in a clock-wise direction to avoid the possibility of unscrewing the rods.

A special type of tool was employed by Dru when boring through a strata which dipped at a considerable angle; great difficulty is experienced in keeping the bore vertical under such conditions when the ordinary trepan is used, and it was found very much better to substitute a circular tool with cutting tools all round the circumference, instead of in one straight line. Thus, at every stroke a positive blow on the higher part of the inclined surface is assured and the whole weight of the tool is utilized in cutting away the high portion. The tool was also made considerably longer in order to form a more definite guide for the cutting face.

Boring with the trepan is usually a very troublesome operation, and is only practised in isolated cases. The tool is cumbersome and liable to damage, and breakages continually interrupt the operations; also owing to the time occupied in removing and replacing rods when the tool is raised, it is liable to be worked for a longer period than is necessary before the removal of the débris and perhaps more than half the working time is employed, not in deepening the bore at all but only in breaking up the material already cut out.

Rope-boring Systems.

In the methods of boring outlined so far the transmission of movement from the headgear to the tool has been through rods. The advantages of rods are that they are rigid, impart a definite blow, may be rotated as required, and have a long life. On the other hand the time occupied in the removal and replacement of rods (each operation being twice repeated) when the tool is raised, the bore-hole cleared, and the tool lowered again, is a serious consideration particularly in a deep

bore-hole of large diameter where heavy tools and rods must be used.

In the original Chinese system of boring, the tool was suspended by a rope so that it could be raised and lowered with great ease at will. But it was found to be well nigh impossible to ensure the verticality of the bore-hole with this system owing to the lack of control over the action of the tool, and the rope was abandoned in favour of rods.

Since then the rope-boring system has been modified and improved, and is again considerably used, especially for oil boring in America. It is important in all boring to maintain constant work at the bottom of the bore, either in comminution or clearing, with as few and short interruptions as possible, and to be able to change tools to suit varying strata with the minimum delay necessitated in raising and lowering.

These conditions are fulfilled to a large degree in rope-boring systems, and their great advantage is the accelerated speed of working which can be obtained.

American Rope-boring System.

In the American rope-boring system the ordinary derrick or sheer frame constructed in wood is usually employed as head-gear, and motion is transmitted through gearing and pulley-wheels to the rope from which the tools are suspended.

The tools are lowered into the bore-hole by the drilling cable, and allowed to rest on the bottom. The drilling cable is then gripped just above the working stage by specially designed jaws at the end of an adjustable connecting tool, termed the temper screw. The working line is attached to the other end of this temper screw, and passes over the drilling wheel to a crank which, when rotated, usually by steam power, communicates a reciprocating motion to the tools.

The sand pump for clearing the bore-hole is slung from a separate block and works independently of the drilling tools, thus avoiding the necessity of dismantling the line of tools each time they are raised, and the sand pump lowered for clearing the débris. The guide pulleys for the drilling cable must be fixed in the sheer frame at a sufficient height to allow the line of tools to be raised clear of the bore-hole.

The same plant is used for driving lining tubes by means of a monkey, working in guides, and suspended from a cable

passing over the drilling-cable guide-pulleys down to the bull-wheel. Reciprocating motion is imparted to the monkey through the cable in a similar manner to that already described on p. 54, or by the rotation of a crank.

Before drilling is commenced lining-pipes are usually driven for a depth of about 30 or 40 feet, depending upon the nature of the ground, to act as a protection to the sides of the bore-hole in the loose strata near the surface, and also to form a guide during the operations. Drilling then proceeds generally on the lines already described on p. 60. A centre-bit or chisel is used first, followed by a rimer to true up the bore-hole, and then by the shell-pump to remove the débris: it is sometimes necessary to use the shell-pump between the chisel and the rimer. The chisel is usually worked at about 30 strokes per minute and must be rotated between each stroke.

The temper-screw, already referred to, forms the connection between the rope supporting the tools and the rope connected to the working beam, and is designed to provide the necessary adjustment in length as depth of the bore-hole increases.

The usual difficulties have to be contended with as regards tools broken in the bore-hole, and the measures adopted in recovering them depend upon the circumstances. A broken rope, generally, does not cause so much delay as a broken rod in other systems.

The American rope-boring system may be taken as suitable for small and medium diameter bore-holes of moderate depth where hard and difficult strata is not anticipated. It is a considerably cheaper form of boring than systems employing rods.

Boring by Hydraulic Wash.

In cases where sufficient water is available the hydraulic washing system is a very convenient method of boring through loose soils or gravels. Hollow boring rods connected to a chisel with water tubes in it are used, to which a vertical percussive motion is given by a steam engine, as already described for other methods. Water is pumped through the rods to the bottom of the bore-hole, passes out through the chisel, rises in the bore-hole outside the rods, carrying with it the comminuted material, and overflows into settling tanks

at the top. After settlement and clarification the water may be used again.

Although this method has been proved efficient on a number of occasions, it is not very widely used owing to the difficulty of obtaining sufficient water to ensure a constant supply at full pressure at the bottom of the bore. When it can be used there is a great economy in time since the tools need be raised less frequently and in addition a clean working face for the chisel is maintained at the bottom of the bore-hole.

It will now be apparent that percussion systems generally are well suited for boring through what may be termed normal strata. The system is simple in operation when ordinary precautions are taken, and does not require a lot of labour or exceptionally expensive plant. But when extremely hard strata are met the cost of boring increases very rapidly owing to the slow progress and damage to tools, and for such cases rotary boring possesses many advantages. Also, although a rough estimate of the strata traversed may be made from the comminuted material brought to the surface, yet this affords no accurate information of the exact thickness and nature of the strata, and for any boring where such information is required the percussion system cannot compare with rotary boring.

Rotary Boring.

The rotary system of boring is only occasionally used when boring for water in this country, for sufficient water is usually found at depths which do not justify the use of rotary boring machinery. In America the system is largely used for oil borings where great depths are attained.

The rotary drill is most successful in firm and hard strata, but the percussion system is better for gravel or sand strata. This originally necessitated a change from one system to the other on each occasion that the strata changed in character, and eventually led to the use of joint-purpose machines which could be used for percussion or rotary drills, the change being carried out in a very short time.

The ordinary rotary drill consists of a circular hollow head with "diamonds" fixed in the lower circumference. When rotated this cuts through the strata and a "core" rises up the hollow tube into a core-barrel. From time to time the

core is broken off, the tools raised and the core extracted. Water fed into the bore-hole acts as a lubricant to the drill and carries off loose débris.

The cutting stones are an amorphous variety of diamond, usually called carbons, and are only valuable on account of their extreme hardness. The best type are the "carbonados" from Brazil, which are usually larger and sharper than the "borts" obtained from South Africa. The carbons need to be set in the crown by an experienced workman who understands what is required, for the cutting qualities of the drill depend entirely upon the setting of the carbons to obtain a sharp and even cutting edge, and so that they shall not become broken or dislodged. If a carbon should fall out of the crown it is recovered by lowering a rod with a pad of wax on the end and pressing on the bottom of the bore-hole.

Hollow-drawn steel boring rods are used, connected at the surface through bevel gearing to some form of motive power. Steam generally supplies the power, but if the current is available electric motors are both more suitable and more convenient in use.

Above the rods a water-swivel is fixed to allow the necessary water to pass through the rods to the bottom of the bore, and the whole line of rods and tools is suspended from a block at the head of the water-swivel. A rope passes from the block over a pulley at the head of the sheer frame or derrick and then to the winding engine. Counterbalance weights are provided to take part of the great weight of the long line of rods off the boring crown. The derrick should be high enough to allow at least 30 feet or 40 feet of rods to be removed together. Owing to their excessive cost, carbons have now been replaced very largely by hard steel cutters or by steel shot working in a special crown, particularly for borings of large diameter, when the cost of the carbons might be considerably in excess of the cost of the remainder of the plant.

The Rotary Shot and Percussion Boring Plant.

Chilled steel shot is now largely used in place of diamond core drills and the plant is so designed that rotary or percussion drilling may be adopted at will as different strata is reached.

The head-gear and rods are similar to those used in rotary

drilling, but the swivelhead is designed so that chilled steel shot may be fed through the hollow rods to the crown. A plain crown, fitted below the core tube, rests on the bottom of the bore-hole and is designed to allow the shot to cut a path as it rotates. For the softer rocks a steel tooth crown may be used without shot, and for soft clay, sand, or gravel beds the hydraulic-wash system with hollow chisels may be resorted to (see p. 67) by simply substituting chisels for the crown and bringing the necessary gearing into operation to give a reciprocating instead of a rotary motion to the tool. Thus the most economical method may be chosen to penetrate each strata, and from the cores an exact record is obtained of the depth and character of the strata. For prospecting and geological purposes this is an important consideration, although perhaps not so necessary on other occasions.

The above types represent, generally, the principal rotary boring machines although special purpose machines are designed and made for particular work. In an experimental machine recently tested in France the water is fed outside the boring-rods and rises from the bottom of the bore-hole through the hollow rods, a reversal of the usual procedure. The principal advantages claimed are (1) that less water at lower pressure is needed, and (2) débris is brought to the surface very much more quickly than by the usual method, with the result that a more accurate idea of the strata traversed is obtained and the bottom of the bore is kept cleaner.

Portable Rotary Boring Plant.

A light portable rotary boring plant is also in use now, in which the drill is worked by two or more men standing on a small metal platform, about 5 feet diameter, which is fixed directly to the lining tubes above ground level. As the boring progresses the weight of the men causes the lining tubes to sink, so that boring and lining proceed concurrently and the auger is never in advance of the lining tubes. Its principal use is for drilling small trial holes for ore deposits when no great depth is required.

CHAPTER VI.

BORE-HOLE PUMPS.

The true artesian well in which the water rises naturally to ground level is only rarely found ; usually it is necessary to adopt mechanical means for raising the water. In the shallower dug wells, where the suction lift from the pump to the lowest water-level is not more than about 20 feet, the ordinary reciprocating or centrifugal pump may be used, but in deep-bored wells some different form of pump must necessarily be adopted in order to avoid the prohibitive expense of constructing a shaft large enough to contain the pumps at a depth within about 20 feet of the lowest water-level.

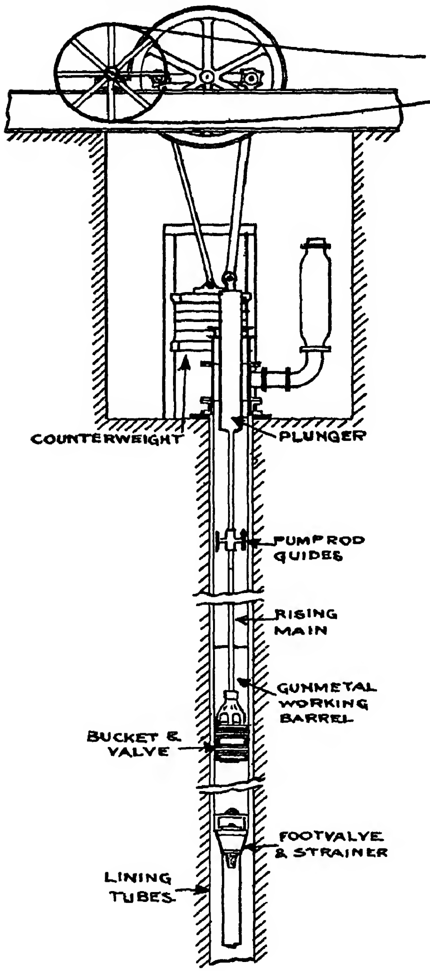
Theoretically the maximum suction lift should be 33 ft. 10 in. or the height of a column of water necessary to balance the normal air pressure of 14·7 lb. per square inch. That is to say, after exhausting the air in the suction pipe the pump should theoretically lift the water when situated about 33 feet above water-level. But in practice it is found to be impossible to obtain such a complete vacuum, and this together with friction losses, limit the suction lift to about 25 feet if the pump is to work satisfactorily.

In shallow wells where the pumps may conveniently be situated within 25 feet of lowest water-level almost any form of pump may be used which is found to be most suitable for other reasons.

In isolated cases it has been found advisable to sink a shaft even 100 feet deep and fix centrifugal pumps in the bottom with the suction pipes in a shallow well which may be connected by a tunnel to bore-holes from which the main supply of water is obtained. This method has been successfully used at Rockford, Illinois, where the pumps are driven, through rope transmission, by electric motors situated at ground level. Again at Rheims a centrifugal pump was suspended in the shaft of the well below lowest water-level with its axis vertical and driven through a vertical shaft 52 feet long by a vertical-spindle electric motor. The average

delivery of this plant was from 25,000 to 30,000 gallons per hour.

FIG. 29.



Bore-hole Pump

Generally, however, the only cases where such arrangements are adopted are where the shaft is already existing, at least for the greater part of the depth required, and where additional pumping is necessary. When a new supply is tapped at a considerable depth it is almost invariably advisable to install special bore-hole pumps.

It is not proposed to discuss here the ordinary reciprocating or centrifugal pumps, which may be used at ground level or in a well of large diameter, but to limit the remarks to a description of specialized practice in the methods of raising water from deep bore-holes.

Lift Pump

Simplicity and strength of construction are perhaps the two most important considerations in the design of a bore-hole pump, and the modern lift-pump, which is the most common form, is an extremely simple affair; it very rarely requires

attention and may be dismantled with comparative ease when necessary.

It consists of the pump, rising main and head-gear (see Fig. 29).

The pump includes a short length of suction pipe, reaching to below the lowest water-level, attached to the end of a gun-metal working barrel which contains the foot valve and strainer and the bucket (see Fig. 29). The bucket is connected to a series of wooden or steel tubular pump rods, which may terminate in a plunger at the top of the rising main, the plunger being attached by a connecting rod to the crank, which may be driven through gearing by any convenient form of motor.

The rising main will, of course, be inside any bore-hole lining tubes which may have been fitted in boring the well.

The top gear consists of the engine or motor to drive the pump through gear-wheels, together with counter-weights and air-vessel. The action of the pump is as follows: on the up stroke of the bucket, which is an airtight fit in the working barrel, a partial vacuum is formed in the working barrel; the valve in the bucket is kept closed by the weight of water above, but the foot-valve is forced open by the air pressure on the surface of the water outside the working barrel and so water enters it to fill the partial vacuum. At the same time the water in the rising main is lifted by the upward motion of the bucket, and half of the volume lifted is delivered to the storage tank while the other half displaces the plunger. On the down stroke the descent of the plunger displaces this latter half of the volume, and delivers it to the storage tank so that a continuous delivery of water is obtained, since delivery takes place on both up and down strokes as in a double-acting pump. At the same time as the bucket descends the foot-valve is closed, and the pressure in the working barrel opens the valve in the bucket and water is forced through this valve into the rising main ready to be delivered by the next up stroke. The air vessel assists in equalizing the discharge and diminishing shocks in the usual manner, and balancing weights are provided to counterbalance the weight of the pump rods and column of water above the bucket. Messrs. C. Isler & Co., Ltd., manufacture a special balancing device whereby the counter-weighting is effected by means

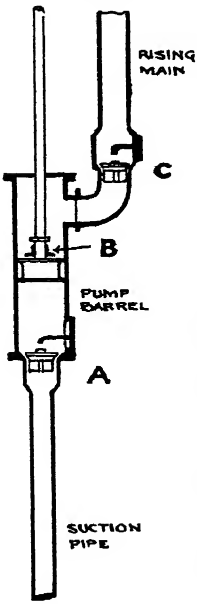
of hydraulic and pneumatic pressure and may be varied to suit the water-level in the bore-hole.

In a well-designed bore-hole pump, the pump should be out of centre with the crank-shaft so that on the up stroke the pull on the pump rods is nearly vertical.

It is sometimes found convenient and economical to provide two bore-holes with pumps driven by one set of gearing and one motor situated centrally between them.

Owing to the weight of the moving parts the speed of the pumps must necessarily be slow, usually varying from about 20 R.P.M. on small pumps to 10 R.P.M. for large sizes, which means a considerable reduction between the motor and the pump. When steam or oil engines are employed the gearing down may be suitably arranged through a system of belts and gearing, but when an electric motor is to supply the power, worm-gear drive appears to be most suitable. For an electric motor drive a fairly heavy fly-wheel should be provided to equalize the torque over top and bottom dead centres, and so keep the current consumption as nearly constant as possible, and prevent excessive overloads.

FIG. 30.



Lift and Force Pump.

Lift and Force Pumps.

Instances frequently occur where an existing dug well, perhaps of considerable depth, yields an insufficient supply of water and a bore-hole is sunk from the well to increase the supply. In such a case a type of pump known as the lift and force pump may sometimes be used with advantage.

The lift pump described above is necessarily somewhat inefficient owing to the length of the column of water which must be raised on each up stroke, and the momentum developed during the down stroke.

In the lift and force pump this difficulty is overcome by placing the rising main on a branch from the pump barrel and introducing a third valve as in Fig. 30. The three valves are

then called the suction valve (A), bucket valve (B), and delivery valve (C) respectively. On the up stroke water enters the suction pipe and pump barrel, and at the same time the portion above the bucket is raised, as in the lift pump, the bucket valve being closed. On the down stroke, however, the weight of water in the rising main closes the delivery valve, so that the weight of this column of water is not acting on the bucket. As the bucket moves down the pump barrel, the water in the pump barrel is compressed, the suction valve closes, the bucket valve opens, and water passes above the bucket ready to be lifted by the succeeding up stroke.

The suction lift in this type of pump is, of course, limited to about 25 feet as in any other type.

Steam Pump.

The direct-acting steam pump may also be adopted as a bore-hole pump, but is not usually recommended. This type of drive may occupy less space at the top of the bore-hole than the ordinary lift pump driven through belts or gearing, but it necessarily works at a higher speed with consequent uneven action and great wear on the valves. Also the steam consumption is high compared with the work done.

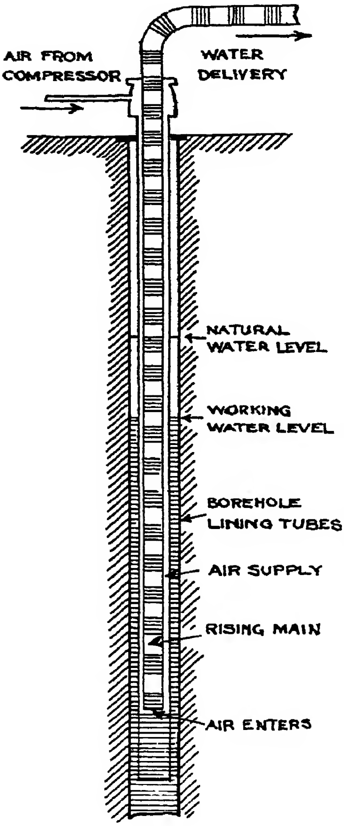
The principle of action is similar to the ordinary steam pump, but the steam cylinder is placed vertically over the bore-hole, and connecting rods extend down to the bore-hole to the pump barrel situated at the bottom, as in the lift pump.

The Air-lift.

Although the air-lift pump has been extensively used in America it has only come into general use in this country during the last few years, and has only recently been appreciated as particularly applicable to raising water from deep bore-holes Only a small amount of space is necessary to contain the component parts, and, although the efficiency is relatively low, larger quantities of water can be raised than by the ordinary lift pump. The absence of moving parts and valves is an important feature and it is unlikely that the pump will become clogged even though large quantities of sand or mud should be present

The air-lift is very useful in small bore-holes, and also for testing a supply before installing large pumps, and it is interesting to note that the system was very largely adopted during the Great War, 1914–18. In a paper entitled "Water Supply with the British Armies in France and Flanders", read before the Institution of Civil Engineers in 1920, Brevet-Major H. S. Briggs says: ". . . the air-lift had become general as a means of raising water from bore-holes in the chalk. Far more water could be got with the air-lift from a 6 in. hole than by any other means, the piping could be installed very rapidly and there was almost entire freedom from breakdown. The lower efficiency compared with the usual type of bore-hole pump was ignored. What was wanted was something that could be quickly installed and that would not afterwards go wrong, and these requirements the air-lift plants fulfilled."

FIG 31.



Air-lift.

The only component parts of the plant are the air-pipe, delivery pipe, and air compressor (Fig. 31). The two pipes, one contained inside the other, are placed in the bore-hole so that the bottom of the air-pipe is about as far below the ground water-level as the water-level is below the delivery outlet at ground level, but allowance must be made for any fall in ground water-level due to pumping and for friction both of air and water. It is important that the air-pipe should extend to the correct depth, as if it is too short the air pressure will be insufficient to give

the water the necessary lift, and if too long the air must be delivered at a higher pressure to overcome the column of water above the bottom of the air-pipe, and will result in uneconomical working. The sizes of air and delivery pipes must also be correctly proportioned, and the delivery pipe must be capable of discharging the required volume without excessive friction losses. The outer pipe should extend at least 10 feet below the inner.

When the plant is not working the water level is, of course, the same in the bore-hole, the air-pipe, and the water-pipe. The compressor being started, air is delivered to the annular space between the air-pipe and delivery pipe, and gradually overcomes the head of water until the surface of the water in the air-pipe has dropped to the bottom, when the air escapes up the central delivery pipe and lifts the water to the desired height. This action continues as long as the compressor is worked, and results in a perfectly even flow at the delivery outlet.

Although, in the illustration the air is shown to be delivered in the annular space between the two pipes, the central pipe may be used for the air supply and the outer pipe for delivery. By perforating the air-pipe near the bottom, a perfectly constant delivery may be obtained, and this also has the effect of increasing the efficiency and aerating the water; but the total area of the perforations should equal the area of the delivery pipe.

The pressure at which the air must be delivered depends, of course, upon the ground water-level and submergence of the air-pipe, but for a total lift of 100 to 110 feet it would be necessary to deliver air at a pressure of about 70 lb. per square inch.

The system is admirably suited to bore-holes of small diameter, and will lift the total yield of the bore-hole, but it is not usually to be recommended for a total lift of more than 250 feet.

Centrifugal Pumps.

The centrifugal pump has now been successfully adapted for raising water from deep bore-holes, and even though the diameter is small—6 inches and above—this type of pump may be used on many occasions with advantage. Before

attempting to install a centrifugal bore-hole pump, it is important to ascertain that the bore is vertical. If the boring is a bad one the rotating connecting rods of the pump may foul the sides of the bore, and so preclude the use of this type of pump altogether. The efficiency of a well-designed centrifugal pump is probably greater on the average than that of the simple bore-hole lift pump, and for a given size of bore-hole will often deliver a greater volume of water.

The reciprocating motion of a long line of pump rods in a lift pump, with the attendant heavy balancing weights, necessarily results in very slow moving mechanism, and seems to compare unfavourably with the clean, light design of the rotary pump. The absence of valves is also an important feature, for worn valves or the presence of foreign matter on the seatings quickly results in a loss of efficiency.

The bore-hole centrifugal pump is made on exactly similar lines to the ordinary rotary pump, but works on a vertical spindle with horizontal impellers. The pump is fixed with a flange joint on the end of the rising main at the bottom of the bore-hole or other desired level, depending on the water line, so that it may be self-priming and the driving shaft is contained inside the rising main and is held by guides. For low lifts a single stage pump with one impeller is sufficient, but for higher lifts of 150 feet or more a multi-stage pump is usually necessary, especially if the bore-hole is small, with perhaps four impellers arranged in series to suit the conditions.

When the diameter of the bore-hole is very small an axial flow-pump is found to be more convenient owing to the smaller space occupied by this type.

Special provision must be made to take the thrust on the pump bearings due to the long line of driving shaft and weight of water. In the centrifugal bore-hole pump made by Sulzer Bros. a thrust bearing is provided at the top of the shaft, but in addition a small piston is keyed on to the shaft in the pump itself in such a manner that the force of the water balances any thrust when the pump is working, so that the thrust bearing is only necessary for starting up before the delivery attains its full velocity.

The question of driving the pump is important since a centrifugal pump is a high-speed machine and only efficient when a certain speed is maintained. Bore-hole centrifugal

pumps often run at 1,000 or 1,500 R.P.M., so that gearing or belt drive is necessary if the prime mover used runs at about 300 or 400 R.P.M. Practically any form of engine which is found convenient may be used, and, if desired, the vertical shaft of the pump may be driven directly from the horizontal shaft of the prime mover through special bevel gearing to give the required ratio.

When current is available at an economical rate, the electric motor is well suited to drive these pumps. Often a vertical spindle motor may be used directly coupled to the pump shaft, running at the same speed and conveniently mounted above the bore-hole in a small motor-house. Such an arrangement forms a particularly compact and simple design, and only necessitates a very cheap and small motor-house to contain it.

Water Elevators.

When a rapid or temporary pumping installation, or a pump for country houses, of comparatively small capacity is required for raising water from a well up to 200 feet or 250 feet total lift, some type of water elevator may be found satisfactory.

Band and " Chaine hélice " water elevators were extensively used in France during the War, 1914–18, and were found very satisfactory and efficient.

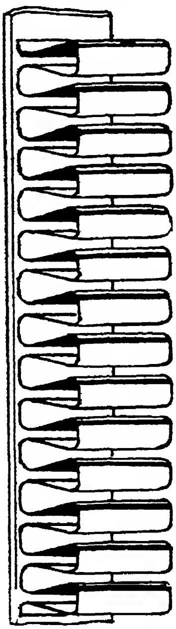
The Band pump consists merely of an endless strip of stout canvas revolving on a drum situated at ground level and suspended in the well so that the lower end is submerged in the water at the bottom of the well. As the band is rotated, water travels with it by virtue of surface tension and is raised. As it passes over the drum at the top of the well the water is thrown off by centrifugal force, and is collected by a hooded trough. The chaine hélice is similar in action, but a spiral of stout wire takes the place of the band.

M. Caruelle has now developed the idea of the band pump and has produced a very much more efficient elevator.

As manufactured by Messrs. Boulton & Paul, under the Caruelle Patents, the elevating band consists of a large number of open ended cells formed in thin, non-corrosive metal and fixed to an endless metal or Balata Belt (Fig. 32), which rotates

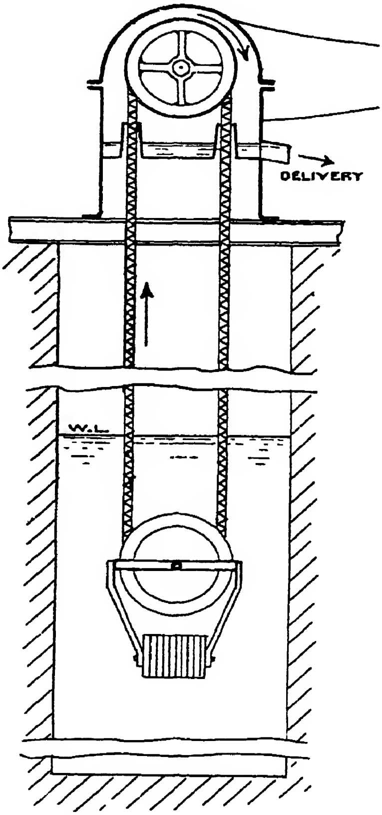
on a drum suspended in the well just as the band pump described above. The cells are specially designed with a high volumetric efficiency so that even at high speeds each individual cell becomes filled with water as it is immersed

Fig. 32.



Detail of Band.

Fig. 33.



Boulton Water Elevator.

and the surface tension causes it to remain full until it passes over the drum at the top of the well, when the water is thrown off by centrifugal force and is collected in a tank. So long as the band is vertical, each cell will hold water even when

stationary, so that the band may be run at slow speeds and a high efficiency maintained. But as soon as the band is inclined, as in passing over the drum, the water is released and collected in the delivery tank.

The capacity of the belt is determined by the size of the cell and for a delivery of about 600 gallons per hour each cell is about one inch wide by one inch deep; for deliveries above 1,000 gallons per hour the required lifting capacity is obtained by using a number of lines of cells mounted side by side on the band.

The general arrangement of the pump is shown in Fig. 33. A counterweight pulley at the lower end of the band keeps it taut and prevents twist. Normally the band is submerged for about 3 feet, but a variation in water level of some feet makes but little difference in the power absorbed.

The drive may be by hand for small supplies or by any convenient form of power. A delivery of 6,500 gallons per hour to a height of 100 feet requires about 7 B.H.P. with a band speed of 160 R.P.M.

It is, of course, impossible, to use the elevator in a small bore-hole as a diameter of at least 2 or 3 feet is required for working the band, and although it can be used for total lifts up to 400 feet or for a duty of 20,000 gallons per hour, it is not so efficient under such conditions.

The overall efficiency varies between 60% and 70% dependent upon the conditions of working.

For raising water above ground level a combined elevator and force pump is made, so arranged that the force pump is in the same unit as the elevator and driven from the same source of power, with its suction pipe in the reservoir of the elevator.

Wind-driven Pumps.

For country districts or any place where the well or bore-hole is in an exposed position and where the power required is not very great, the wind-driven pump should always be considered. A modern windmill with numerous galvanized iron vanes, although not so picturesque as the old sail type, is more efficient and runs in very light winds, so that if the windmill pumps into a reservoir which provides sufficient storage to ensure a supply of water during exceptionally calm

periods, there should be no difficulty in maintaining the supply. This type of power is, of course, suitable only for small supplies and small lifts.

The vanes are sometimes arranged so that the angle of incidence may be varied to suit the strength of the wind, and are kept facing the wind by the action of a stationary vane or subsidiary fantail. The whole of the control should be from the ground.

CHAPTER VII.

NOTES ON WELLS AND BORINGS.

Well at Trafalgar Square, London.

THE wells supplying the fountains in Trafalgar Square possess both general and technical interest. The water is supplied by two wells connected together by a tunnel in the clay at a point lower than the position in the wells to which the water rises. The wells and tunnel were originally calculated to hold 122,000 gallons when the water had attained its maximum height. One of these wells is in Orange Street, and about 180 feet deep, with a diameter of 6 feet; the other is in front of the National Gallery, and is of very nearly the same depth, with a diameter of 4 feet 6 inches; the driftway is 6 feet diameter, and occurs about 5 feet from the bottom of the shafts; this driftway, or tunnel, is horizontal. The boring, which commenced at the bottom of the shaft, was continued to a greater depth in the well opposite the National Gallery than in the one in Orange Street; the total depth from the surface being, in one case, 395, while in the other it was about 300 feet. The use of the tunnel is almost self-evident; it acts, as may be supposed, as a reservoir to store the water while the engine is not at work, thus insuring a sufficiency to supply the pumps, even should they draw the water away from the well faster than the same is supplied by the spring. The strata passed through by the two wells may be thus stated upon the authority of a section published in the *Illustrated London News*.

Well in front of National Gallery

	Feet.
Made ground	9
Gravel	5
Shifting sand	7
Gravel	2
London clay	142
Thin layer of shells.	
Plastic clay	30

Well in Orange Street.

	Feet.
Made ground	15
Gravel	5
Loam and gravel	10
London clay	145
Thin layer of shells.	
Plastic clay	30
Gravel and stones	10

Well in front of National Gallery.

	Feet.
Greensand, pebbles, etc. .	11
Greensand	42
Chalk	

Total depth to chalk is therefore 248 feet, and total depth of well and bore 395 feet.

Well in Orange Street.

	Feet.
Greensand	35

Chalk, which, according to the above, is distant from the surface 250 feet, the bore being continued to a total depth from surface of ground of about 300 feet.

There were originally two other wells, which are now disused, and which used to supply Government buildings in the neighbourhood, but both the water-level and the yield fell rapidly. When the well outside the National Gallery was completed in 1847 the water-level was at — 70 O.D. or 150 feet above the top of the chalk, but it has fallen 115 feet in sixty-four years and at present is well below — 200 O.D. Thus the head on the chalk is considerably reduced, resulting in a corresponding reduction in the yield from the chalk, which being dense transmits the water with difficulty. Water is present in the sands above, but owing to the lack of pressure does not penetrate the chalk with the same facility, and so does not reach the bore-holes. This is a confirmation of the fact that the chalk itself is not very permeable, but depends largely upon fissures or beds of flint for the transmission of water.

Artesian Well at Camden Station.

This well is sunk to a depth of 180 feet, with a diameter in the clear of 9 ft. 6 in., and the steining is executed throughout the entire depth in cement. For 28 feet from the surface, unusual precautions are taken to exclude land-springs, etc.; they are, first, an inner steining of half brickwork set in cement, next, segmental cylinders of iron; next, a thickness of about 9 inches of concrete; and lastly, behind all this, a 9 in. steining of brickwork. From the depth of 28 feet from the surface, the steining is 14 inches thick, and bonding curbs of iron occur at intervals. The boring, which commences at a depth of 180 feet from the surface, is continued for 220 feet, and is of a diameter of 12 inches. The water rises in the well 36 feet from the bottom, or to a

height of 144 feet from the surface of the ground. The ground passed through in the execution of this well was as follows :—

STRATA TRAVERSED.

	Feet.
Made ground	9
Loam and gravel	6
Black earth	3
Blue clay	144
Mottled clay	36
Greensand	1
Pebbles	2
Mottled clay	8
Plastic clay	17
Loam and sand	5
Pebbles and sand	2
Bed of flints	1
Chalk	166
Total depth	400

The boring-pipes are continued 60 feet up the well, the water being admitted from them by a sluice, which is situated about 4 feet from the bottom of the shaft. This sluice is worked by a handle placed above the water-level; the pipes themselves are steadied by stays, which are secured to the brickwork of the well.

Well at Kilburn.

This well and bore-hole provides a good example of typical work of its kind. The diameter in the clear for 250 feet in depth is 4 feet; after that, boring commences, and is carried down to the sand-spring at a diameter of 8 inches, and to a total depth from the surface of about 280 feet. The rise of water was to about 150 feet, or rather less, from the surface The original intention in sinking this well was to have bored after attaining a depth of 200 feet (the water-level being well known in this district), but had such intention been persevered in, fears were entertained that the 50 feet of water in the well, being only the upper head of the spring, would be insufficient to supply the wants of the brewery; the extra 50 feet of digging were therefore ultimately determined on, and the experiment detailed in the following pages proves the view taken to have been correct: for if pumps be fixed at too high a level above the spring, the hydrostatic pressure of water is insufficient to cause the

water to rise in the well fast enough to supply the pumps, even should they be small ones. For the first 10 feet the brickwork was 9 inches thick in cement, to exclude land-springs from the well: about 25 feet were executed the first week, and after that the work averaged about 20 feet to the week, some weeks a little more, some a little less; the stiffness of the clay and the claystones, or septaria, which were found at intervals, affecting the speed of the work. The London or blue clay, which was soon arrived at, extended to a depth of 235 feet—the mottled clay, pebbles, and sand followed much in the order of the sections before given—while in the mottled clay the steining was not left unsupported with such impunity as in the blue clay; it is of a more soapy or slimy nature, and exposure to the air, together with these properties, renders it more likely to allow the brickwork to slip. On the execution of the steining it is only necessary to remark that the work was laid partly in cement and partly dry, and of a thickness of 4½ inches. The boring-pipes were of wrought iron, the lower lengths perforated, the junctions being tinned in the usual manner. On obtaining the water, the quantity was tested by the aid of a temporary pump, the application of which is also useful in clearing the work, and ascertaining if any sand has blown into the well; this pump was an ordinary lifting pump of 6 inches diameter, and working with a stroke in the barrel of about 9 inches; the rising main was bolted directly over the pump-barrel, which was thus suspended in the water; the main, on its passage up the well, was steadied by timbers; the rods worked by this arrangement in the rising main, and were carried to the top of the well, where motion was given to them by eight men; the result of the experiment was that the pump, which threw about 24 gallons per minute, lowered the water about 33 feet, but no further, thus proving the strength of the spring when a head of 33 feet of water was taken off. Here the advantage of drawing the water from a point under its surface, as far as practicable, is made manifest; indeed, the question is one turning on a law of hydrostatics, well known and easily calculated. The pumps were executed by another party, and it may suffice to say that they are of the description technically called three-throw pumps, and very good of their kind. The cost of

executing this well, exclusive of the pump work, both temporary and permanent, was about £200.

Well at Hampstead Heath.

This well was sunk down to the main sand-spring, a depth of about 320 feet, and of a diameter of 7 feet. Subsequently, as a rather greater supply of water was desired, a bore was carried into the chalk. The steining of the well is 9 in. work, laid dry, between rings set in cement; the back steining has its cement rings midway between those of the front steining. The lower part of the steining is held up by four tie-rods, which are bolted to a cast-iron curb let into the brickwork some distance up the shaft. The section of the ground passed through during the two operations of digging and boring is given below. The situation is on the lower Heath, where the Bagshot sands are wanting.

	Feet.
Yellow clay	30
Blue clay	259
Plastic clay	40
Sand	49
Bed of flints, very thin, chalk hard . .	40
" " soft, with water . . .	4
Chalk, hard, no water	28

From this section it will be seen that after passing the chalk spring, the hard chalk underlying it supplied no water, thus proving that in sinking wells in this formation, when it is very hard, no water can be expected till long lines of flints, fissures, or softer chalk, are arrived at.

The arrangement of pumps in this well illustrates the principle of lifting the water in stages. More modern pumps would be installed in new wells now, but many old wells where a shaft is available are equipped in this manner. The water is raised in this well by means of three lifting pumps, situated at different heights up the shaft. Each lift averages about 100 feet, and the sizes of the pumps are $8\frac{5}{8}$ in. diameter of bucket, by a length of stroke of 2 ft. 3 in.; the lowest pump is slung in the water by having its rising main, which is of larger diameter than the bucket, secured by flanges and bolts to cast-iron girders, arranged for that purpose in the well, where the two lower lifts terminate. The pump-rods pass through stuffing-boxes from inside the

rising main. The cisterns, from which the second lift draws from the first, and the third from the second, are very small, being only branched from the rising main, and in capacity but little larger in diameter than the pump-barrel, just in fact sufficient to hold a supply for the higher lift. The rods, when inside the mains, are steadied by triangular guiding pieces encircling them, and where outside the mains, they pass through wooden cleats, which are secured to cast-iron girders. Situated at the top of the well is a cast-iron framing, with upright guides. Between these guides work cast-iron wheels; to the axle of these wheels the pump-rods, and also the connecting rods from the cranks, are attached; thus, though the tendency of the crank in its revolution is to pull the rods from a vertical line, the effect of the pulleys is to keep their motion in a straight one.

Many wells in the Hampstead district are now disused owing to the insufficient supply of water; in fact, a well at the Hampstead Brewery was actually used for storage of water and the loss or increase was inappreciable, proving the chalk to be almost impermeable here.

Stratification and Ground Water near London.

In areas where the water-bearing strata is at a considerable depth the yield of water is often much lower than the normal for that strata owing to the increased density of the formation due to the superimposed heavy load. Good examples of this are provided in the Hampstead and Richmond Hill districts.

In each of these areas a local syncline is overlaid by an exceptionally high surface ground level. A syncline is normally regarded as favourable for a good supply of water, but in these cases the heavy overload appears to have had the effect of consolidating the Thanet sands and the chalk, and so increasing the friction to such an extent that the flow of ground water is seriously reduced. The actual water-level may be found quite normal when the well is sunk, but after comparatively little pumping the yield falls rapidly, for the percolation of water through the sand or chalk towards the well is insufficient to make good the depletion. Thus, many failures are recorded in these areas and the yield is strictly limited in wells which are in use.

It has been suggested that the water in such areas as the

London Basin, which has been considerably depleted by over-pumping, might be replenished if a suitable method could be found of conveying surplus water into the chalk, or of artificially increasing the outcrop area. This was actually done by the East London Water Company in taking water from the Lea River and, after filtration, sending it into large galleries leading to the chalk. Such a quantity was introduced that the operation was quite successful, and the ground water level in the district was not only maintained but raised for a considerable period of time.

Dumb wells have been mentioned as a suitable means of introducing water into the sand and so to the chalk. It was considered that in this case no filtration of the water would be necessary since the sands would provide sufficient purification.

Some important observations may be made upon the results of the wells described above, all of which are sunk in what is called the London Basin. Firstly, in the case of the Camden Town well, the quality of the waters is such as to show that the whole supply is furnished by the loam and sands of the basement beds of the London clay. The boring in the chalk, under these circumstances, was worse than useless, for it only let the water from the sands into a part of the subjacent formation, which was likely to be more absorbent than the surface, because at the junction of any two strata there usually exists a layer of silt or clay which renders the escape of water from the upper to the lower rather difficult. This well may be considered as having been carried down 166 feet deeper than was necessary.

Secondly, in the chalk itself there does not appear to be any other indication of the flow of water sufficient to guide the operations of the engineer than what is furnished by the materials traversed. The water circulates through it principally along the lines of fissures, and not by general permeation of the whole mass, owing to its general impervious nature and its close texture. It happens, however, especially when it underlies some impervious stratum, that the body of the chalk itself is saturated with water, and a portion is left free to circulate upon any retentive layer which may exist within it. The layers of flint, which sometimes occur in regular stratification over large areas, serve

to hold up this free portion in the upper or soft chalk; and it therefore must be upon the top of these layers that we must seek for a supply to a well sunk in this formation, unless any water-bearing fissure be traversed. In the lower members of the series the comparatively speaking impervious beds of the chalk marl perform the same function of water-bearing strata that the beds of flint do in the wells sunk nearer London.

The water-bearing capacity of the district is also largely governed by the area of outcrop of porous strata. Thus on the south side of the Thames towards Croydon the area of clay overlying the chalk is very much less than north towards Bushey and Uxbridge, and also right up to Southwark and Rotherhithe there are extensive beds of gravel at the surface, which are only separated from the Chalk by the Thanet Sands. Again the chalk is much nearer the surface on the south side than on the north. In many places on the south the sands are exposed within a few miles of the Thames, whereas on the north side there is no permeable strata exposed until the Watford and Barnet district is reached.

Thus the supply of water to the London basin on the south is considerably larger than on the north, with the natural result that the ground water-level is higher on the south than on the north. There is a distinct fall in the water line at all points where the surface supply is interrupted by the impervious covering of clay, and the water-level gradually falls westward along the Thames Valley from Greenwich. At Mortlake the effect of this is very noticeable; in a well here the water-level fell nearly 250 feet in about 40 years, owing, no doubt, to the restricted supply from the north together with the effect of the fault to the south-east previously described (see p. 40).

It may be noted that the gravel beds in the Thames valley to the east of London seem to cause pollution of the chalk water in the neighbourhood, and this pollution is liable to extend in course of time further westward, especially as the water-level is lowered. Analyses show an excessive proportion of solids and of chlorine, suggesting the infiltration of water from the Thames. This can, of course, be effectually cut off from wells in the affected area by carrying the lining to a greater depth, but this usually results in a reduced yield.

Results in Sub-cretaceous Formations around London.

Attempts have been made on many occasions to obtain a supply of water from the Lower Greensand and Gault formations below the chalk in the London area, but without any degree of success.

Perhaps one of the first of these was a boring sunk at Hampstead. It has already been pointed out that in this district the yield from the chalk is small, owing to its dense nature. The directors of the Water Company were also obliged to seek for a supply that was independent of any natural watercourse; and after consulting Mr. Prestwich, at that time the greatest living authority upon hydrographical geology, they determined to seek through the chalk, in the hope of obtaining a supply from the lower greensands that were known to crop out on the edges of the chalk basin, like the Paris strata did, and that were supposed to be continuous under the chalk. The boring was confided to Messrs. Degoupée and Laurent, who had great experience in this class of work, and had executed some of the most successful wells upon the Continent. The shaft had been already sunk through the London clay and the chalk, to the depth of 530 feet from the surface, at which level the boring commenced, at first with a diameter of 12 inches, subsequently reduced to 10, and finally leaving off with a diameter of 8 inches. The chalk was found of its calculated thickness; the upper greensand and the gault were found to be as they were expected; but at the depth of 1,113 feet from the surface, the boring tool passed into a succession of beds, consisting of alternate layers of red sandstones, red clays, conglomerates, and sands which geologists were disposed to believe were members of the new red sandstone series, instead of the lower greensand that they expected to meet with in this position. The consequence of this was that the boring was stopped, at a further total depth of 1,302 feet from the surface; and the Company was ruined.

Well and Boring at Kentish Town and Richmond.

An attempt was made to obtain water below the chalk at Kentish Town, where the yield from the chalk was insufficient. The boring was carried down to a total depth of 1,302 feet

and passed through the Chalk Marl, Upper Greensand, Gault, and Red Sandstone into what is probably the Old Red Sandstone or Devonian Formation. Water proved to be absent, and the venture was a failure, but scientifically the boring was of considerable interest, since it proved the continuation of the strata from the outcrop further north.

Again, at the Richmond Waterworks similar conditions prevailed as at Hampstead, the chalk being very dense with an insufficient yield. The decision was therefore made to bore to a greater depth. The whole of the chalk was penetrated, and the boring was carried through the Upper Greensand, Gault, Lower Greensand, and Great Oolite into somewhat doubtful rocks, probably of the Devonian, at a total depth of 1,447 feet. Various springs were found during the boring, and at first water overflowed at the surface, but the yield was small and the level very quickly fell, until it was more than 100 feet below O.D., and the boring was pronounced a failure.

Borings have also been taken down to the Old Red Sandstone at Willesden, Chiswick, Becton, and other places, but it seems that in each case the water first overflowed at the surface and then steadily diminished until, some years later, the yield was insufficient. The water obtained also contains, in most cases, excessive proportions of solids and often a large amount of salt, which in the case of Willesden amounts to as much as 1½ per cent.

It is of interest to note that borings recently carried out at Slough reaching the Lower Greensand have struck large quantities of water of a very satisfactory character, and if the supply and purity is maintained this is apparently the nearest point to London where the sub-cretaceous formations have yielded any large supply of good water.

Well at Caledonian Road, London.

This well provides a good example of a typical dug well with a boring below, and the description given represents the method of carrying out this type of work.

In commencing the work five men were employed, who made an excavation 9 ft. 6 in. diameter, which was to allow space for the finished shaft to be 6 feet in the clear, with the 9 in. steining, and 12 inches of puddle at the back, for

more effectually excluding the land-springs. This excavation was carried down to the depth of 10 feet. The 9 in. steining in cement and the puddle were then commenced and completed to the surface. The stratum of clay at this depth was so solid that it was considered that the puddle might be dispensed with; an excavation only 7 ft. 6 in. in diameter, and 5 feet deep, was therefore made, and the back steining only, of half a brick in thickness, completed in cement. Similar excavations of 5 feet in depth were made in succession, the back steining alone in each case being completed, until the solid mass of London blue clay was found at the depth of 30 feet from the surface. The inner steining was then brought up in cement, so as to underpin the first portion which had been completed. The land-springs were found to be effectually excluded, and the work then proceeded in all respects according to the specification. Two additional hands were employed when the well was about 30 feet deep, and no difficulty was experienced until the mass of London clay was cut through, and the upper beds of the plastic clay formation, which were found at the depth of 150 feet, were perforated. Here a stratum of dark sand was found containing a little water. This sand was so loose that it did not afford sufficient foundation for the brickwork; and there was this further difficulty that had the water been pumped out the sand would have been set in motion, or, to use a technical expression, would have blown up in the well. Under these circumstances, it was determined to substitute cast-iron cylinders, 5 feet diameter and 1 inch thick, for the brick steining.

The specification and tender for supplying the cylinders, and executing the work with them, was as follows:—

Tender for supplying cast-iron cylinders to be used in lieu of steining.

Tottenham.

I hereby engage to secure the present brickwork in its place by strong elm ribs, suspended by iron rods up the shaft, and to provide and fix cast-iron cylinders of 5 feet diameter and 1 inch thick, in 5 ft. lengths, with internal flanges, properly packed and bolted together, and to caulk the same with iron cement, and to carry them down through

the upper sand, and drive the lower end firmly into the clay; and to concrete behind the upper cylinder with gravel and cement, to form a footing for the lower steining, and for stopping out water, providing every material required for the work, at £7 2*s*. per foot lineal.

(Signed) THOS. CLARK.

Before proceeding to lower the well or fix the cylinders, it was necessary to secure or tie up the brickwork which had been already executed. For this purpose a strong elm frame was inserted under it, and the frame being connected by 1¼ in. rods with two strong beams fixed over the top of the well, effectually secured the steining in its place. In order to steady the cylinders, and keep them in a right line as the work proceeded, four battens, 20 feet long, 7 inches wide, and 2½ inches thick, were fixed to the lower part of the brickwork, forming a kind of frame through which the cylinders would slide; this being arranged, the first cylinder, 5 feet in length, was lowered to the bottom, and, after being properly adjusted by means of wedges, another was added on the top, and the joint of the flanges made good; four others were added in succession, making a length of 30 feet of cylinders fixed, before the excavation was proceeded with. The object of this was two-fold; first, that the outer surface of the cylinders being confined within the wooden frame already described, the true direction would be maintained; and, secondly, that the weight of the mass would aid in its descent into place as the boring or excavation was proceeded with: by these means, had the stratum proved to be a quicksand, the difficulty would have been overcome. A stage was then placed on the upper part of the cylinders, and an auger, 4 ft. 10 in. in diameter, was introduced within them. Each time that this auger was drawn out the cylinders settled on an average about 2 inches, and no difficulty was experienced. The stratum of sand, which was about 20 feet in depth, was cut through, and a hard mottled clay was found under it; it was essential that the cylinders should be firmly fixed in the clay in order to prevent the water contained in the sand from forcing its way under them and rising into the well. The boring

was therefore continued for a few feet, and the cylinders were at last driven into the clay with a heavy dolly made of the rough trunk of a tree. The water, which had hitherto stood above the level of the top of the sand in the cylinders, was now pumped out, and the well remaining perfectly dry afforded evidence that the water contained in the sand had been effectually stopped out. The 12 in. pipe mentioned in the original specification was dispensed with, and the boring was continued with a 10½ in. auger down to the chalk; 8 in. pipes were then introduced, which were firmly fixed several feet into the chalk, and were left standing 6 feet above the bottom of the cylinders. The object of this latter arrangement was that any sediment contained in the water might settle at the bottom of the well.

The following is a section of this well, together with the distance from the surface of the ground to various points in the well itself:–

	Feet.
Yellow clay and gravel	30
Blue clay	100
Mottled clay	19½
Dark loamy sand, and little water	18
Hard mottled clay, and sand without water	17
Dark sand, with little water	34
Hard flint	1
Chalk	151
Total depth	370½

	Feet.
Distance of bottom of brick shaft to surface	153
,, from top of iron cylinder to do.	139
,, from bottom of iron cylinder to do.	170
,, from bottom of iron piping to do.	230
,, from top of copper piping to do.	220
,, from bottom of copper piping to do	259

On the completion of this well, it was considered desirable to test the strength of the spring by pumping, which operation had also the effect of freeing the sides of the bore, thereby allowing the water to percolate more quickly, as the action of the tools necessarily had a tendency to harden the chalk. The pump was kept at work night and day, a relieving gang of men coming on every four hours. After working in this manner for forty-eight hours, the level of the water in the cylinders was marked, and it was also ascertained

that in one hour rather more than 900 gallons were removed from the well. The water-level was lowered by the pumping 1 foot; and as a hole 5 feet in diameter and 1 foot deep contains 122 gallons, that amount deducted from 900 gives as the water-supply nearly 800 gallons per hour.

Boring at Harwich.

In consequence of the success of a boring at Stowmarket, which is situated on the chalk in the valley of the Gipping, an affluent of the Orwell, that reaches the sea at Harwich, it was decided that an attempt should be made to obtain a supply for Harwich itself (which is situated upon the outer, or seaward, edge of the London Clay) by the same means. Attempts had been previously made to sink wells in this spot, but they had always proved unsuccessful, in consequence of the communication of salt water with the land waters in the operations carried on near the sea-shore; and therefore the local authorities determined to try whether they would be more successful in the attempt to obtain a supply from a deep-seated source such as would be furnished by the lower greensands, which, analogy indicated, would be found under the chalk basin of the London clay. The Stowmarket well had been sunk through the superficial gravels and clay, the chalk formation, the upper greensands, the gault, and reached the water supply in the lower greensand at the depth of 895 feet from the surface; but there was, of course, a considerable difference of level between the position of this well from that undertaken at Harwich. It happened, however, that in sinking the latter well, the men employed found that after they had sunk through the London clay, the chalk, the upper greensand. and the gault, the boring passed at once into a slaty rock of a black colour, which Mr. Prestwich pronounced to be a member of the Cumbrian or Westmoreland slates, although its precise situation in the series could hardly be ascertained, in consequence of the absence of fossils in the materials obtained from the boring. This result was a confirmation of the observations recorded to have been made at Calais, where a member of the pre-carboniferous series was found to exist under the gault, and it confirmed the opinion that the whole of the series of strata between the new red sandstone and the gault were absent

under London, as in the boring at Highgate Hill. Similar results were also obtained at the well that was sunk for the town of Ostend, which is situated in the prolongation of the London tertiaries upon the Continent.

The boring was carried out from a shallow shaft, and the following strata were penetrated :—

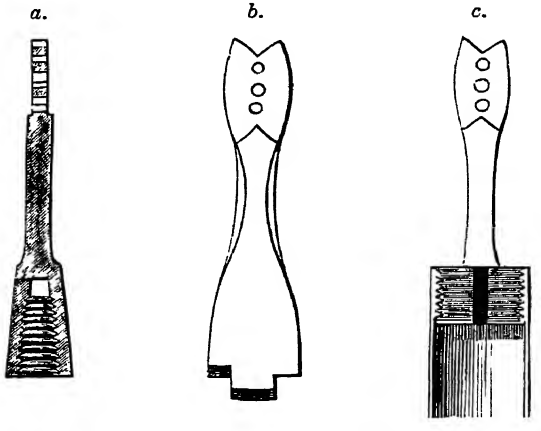
Strata.	*Thickness.* Feet.	*Depth below surface.* Feet.
Earth	10	10
Red Gravel	15	25
London Clay	23	48
Gravel beds	10	58
Plastic clay	7	65
Clay	5	70
Sand	5	75
Blue clay	3	78
Chalk	852	930
Chalk Marl	38	968
Gault and Greensand	22	990
Gault	39	1,029
Slaty Rock (probably Devonian)	69	1,098

Artesian Well at Grenelle.

This well was sunk, at the expense of the City of Paris, under the directions of M. Mulot, for the purpose of supplying the abattoir, and the district or quarter of Grenelle.

At St. Ouen and St. Denis, near Paris, artesian wells had already been sunk through the tertiary formations, until they reached the sands which lie upon the chalk; and a copious supply had been obtained from them. But at Grenelle it was known that so great a difference existed in the geological structure of these formations that it became necessary to resort to some other source. The "calcaire grossier", in fact, of the more northerly parts of Paris is replaced at Grenelle by a series of marls and clays, which do not allow the free passage of the subterranean sheet of water. M. Mulot, then, reasoning upon the results obtained by the wells at Elbœuf and Rouen, considered that it would be necessary to traverse the chalk formation itself and to obtain a supply from the lower greensands. At Elbœuf, where the ground is about 27 feet above the sea, the water rose to about 82 feet above the ground, or 109 feet above the sea. As the plain of Grenelle is 104 feet above that level, M. Mulot thought, very correctly,

that if he reached the same sheet, the water would necessarily flow over the surface. MM. Arago and Walferdin, who brought to M. Mulot's assistance the influence of their scientific knowledge and their great reputation, found in the course of their examination of the district that the level of the greensands at Lusigny, 12 miles above Troyes, where the Seine leaves those formations, was nearly 300 feet above that of the plain of Grenelle. The inference they drew from this fact was that the water would not only overflow the bore-hole, but also rise to a very considerable height above the ground.

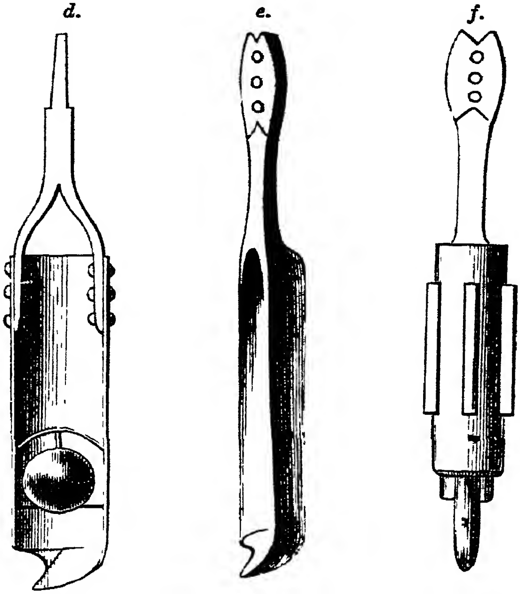


a, is the screw-tap contrived for raising the fragments of the rods from the bore
b, a chisel similar to the one which fell to the bottom.
c, a screwed plug fitting into the tubes, by which these are lowered to their positions.

Upon these reasonings M. Mulot commenced his work; and after eight years of indefatigable labour, in spite of all the accidents of the undertaking and the sneers of the incredulous, on the 26th February, 1841, his perseverance was crowned with the most signal success. The depth attained at the period of reaching water was not less than 1,802 feet from the surface, or about 1,698 feet below the level of the sea. The strata traversed were as follows:—

	Feet
Drift gravel, about	33
Sand, clays, lignites, etc., replacing the calcaire grossier	100
Fragments of chalk in a species of clay .	16½
Chalk	1,378
Chalk marl	88½
Gault clay and greensands	186
Total	1,802

When the water rose to the surface it was ascertained to be of a temperature of 81·81° Fahrenheit; and it remains of that degree to the present day. M. Walferdin, who watched the progress of the work with great interest, made



d, a scoop, with ball clack, for removing wet sand
e, an ordinary shell.
f, an auger for enlarging the bore to place tubes.

a series of observations to ascertain the law of increase of temperature at great depths. He found that at Paris the thermometer remained constantly 53·06° Fahrenheit in the cellars of the Observatory, which are 94 feet below the

surface; in the chalk, at 1,319 feet from the surface, it marked 76·3°; in the gault, at 1,657 feet, it marked 79·61°; thus showing that in depth of 1,553 feet the increase of temperature was 26·55°, or about 1·7° Fahrenheit for every succeeding hundred feet beyond the depth of constant temperature. According to this law, the temperature at the depth of 1,802 feet from the surface ought to have been 81·96° nearly; and that of the waters, stated above to be 81·81°, is a striking illustration of the accurate observations and deductions made by M. Walferdin.

Amongst the numerous difficulties attending a work of this kind, those arising from the rupture or fall of the boring-tools were the most dangerous. Thus, when a depth of 1,250 feet had been reached, a length of about 270 feet of the rods fell to the bottom, and broke into several pieces. It required all the ingenuity of M. Mulot, and not less than fifteen months' labour, to remove the fragments one by one, by the aid of a screw-tap, which was made to fit upon the ends of the rods. In April, 1840, a chisel fell to the bottom, and buried itself in the solid chalk. In this case it became necessary to clear away all round the tool, and to raise it by the same means as before. About three months before the water-bearing stratum was reached a shell also fell to the bottom; M. Mulot pushed this aside, and continued the boring beyond it.

The quantity of water supplied by this well is about 800,000 gallons per day, rising to a height of 122 feet above the ground. The total cost was about 400,000 francs. It is to be observed that even now the rising pipes are occasionally choked with the sand from below.

Drawings of tools used will be found on pp. 98–9.

Deep Well at Passy.

The Paris Municipality was later induced to repeat the successful operation that they had accomplished at Grenelle by sinking a well at Passy. They confided the execution of the works in this case to M. Kind, who had executed some of the deepest wells that had been executed in the Rhenish provinces of Prussia and the neighbouring countries, for the purpose of extracting salt from the brine springs that rose from the marls of the new red sandstones, and who had

established a reputation for the manner in which he had succeeded in sinking the shafts of certain coal-mines through the running sands that are often met with in the coal measures. The first intention of the engineers of the city was to execute the boring of the same diameter as the Grenelle well, that is to say, of 8 inches; but M. Kind undertook to terminate the boring of the diameter of 2 feet, and he also contracted to deliver the water at the height of 92 feet above the level of the ground at the rate of three million gallons per day. This he engaged to effect within the space of two years, and to complete the works for the total sum of £14,000. There were, of course, many opponents of M. Kind, on the score of his nationality and on the score of the increased delivery that was presumed to be attained over the well of Grenelle; but at last the authorities were persuaded to allow M. Kind to go to work with the processes he introduced. This took place in consequence of the vote of the Municipal Council on the 23rd December, 1854. The works were commenced shortly afterwards, and by the 31st May, 1857, the boring had already been carried to the depth of 1,732 feet from the surface, when suddenly the upper portion of the lining of the well collapsed, at the distance of about 100 feet from the ground, and choked up the whole of the boring. This accident led to the failure of M. Kind, and considerably delayed the progress of the works; but the Municipal Engineers were so satisfied with the energy and skill that M. Kind had displayed in the conduct of the works, that they entrusted the conduct of the remaining operations to him upon the resiliation of his original contract. A well was sunk, and lined with masonry, to the depth of 175 ft. 4 in. from the surface, and the boring was then cleared out and resumed. Much trouble was encountered in traversing the strata that were situated below the distance of 1,732 feet from the ground, above quoted: and at length, at about 1,894 feet from the surface, the first water-bearing stratum was met with, but the water, after several oscillations, did not reach the ground The boring was continued below this level until on the 24th September, 1861, at mid-day, the true artesian spring was tapped at the depth of 1,923 ft. 8 in. from the surface. When this spring first rose, it discharged about 5,582,000 gallons per day, but the yield

of the well in its normal state has oscillated considerably. So long as the column was not raised above the level of the ground, however, the total quantity delivered did not vary much from that of 4,465,600 gallons per day. It had been noticed previously that the well of Grenelle had sunk gradually, in consequence, no doubt, of the obstruction of the tubes in it, until the rate of delivery had reached 200,000 gallons a day, instead of 800,000 gallons that it had originally yielded; but it was also observed that the Grenelle well was affected within 30 hours after the Passy well had been continued to the water-bearing stratum, until the yield of the former had settled to the rate of 173,000 gallons in the day of 24 hours. The delivery of the Grenelle well remained stationary at the above rate, so long as the height to which the water was delivered at Passy remained the same as it was originally; but when this was altered, so as to make the points of discharge of the two wells equal in height, the yield of the Grenelle well was resumed, and the yield of that of Passy fell off until it only amounted to 2,000,000 gallons per day. The horizontal distance from the Passy to the Grenelle well is about 3,830 yards, and the depth of the water-bearing stratum is, at Grenelle, 100 feet nearer the mean level of the sea than it is at Passy; while the surface of the ground is about 35 feet higher in the latter locality than it is at Grenelle.

Without doubt the effect produced upon the respective sources of supply, by the alterations in the heights of the columns of water delivered, proves that both the Passy and Grenelle wells are fed from the same water-bearing stratum; nor can there be any reason to doubt but that the Passy well water would be of nearly the same composition as that of Grenelle, when once the passages through which the water flowed were cleared from accidental impurity. M. Pelligot has carefully analysed the Grenelle waters, and he found that they contained 6·000142 of saline matters, composed principally of the carbonate of lime, potash, and magnesia, associated with a compound of sulphur and soda, of variable proportions and conditions, and with the carbonate of the protoxide of iron and silica. The salts of the sulphide of lime, that are amongst the most permanent impurities of water, are entirely wanting; and it would appear that the

gases diffused through the water are of considerable volume, the carbonic acid gas being the most so. There is a sensible evolution of sulphuretted hydrogen from both the well waters of Passy and of Grenelle; and it is worthy of remark that the same gas is given off from the waters obtained by Mr. Gatehouse, of Chichester, though, in this case, the quantity of gas is sufficient to render the water quite unfitted for drinking purposes, which is not the case with the waters at Passy or Grenelle. The temperature of both these sources of supply is about 82° Fahrenheit, which is another proof of their common origin; the Grenelle well, as was said in the text, rising at nearly that degree of temperature. Unfortunately, the tubing that M. Kind introduced in the progress of the work has proved to be utterly untrustworthy, and the consequence has been that the water from the bottom of the boring has communicated with the various water-bearing strata that it encounters in its ascent, thus increasing both the volume and the temperature of the latter, and furnishing a nearer outflow for the waters that it yields than is provided for it upon the surface. Practically the results of the Passy well were, originally, without any result; though the cause of this was well known, and could be remedied by simply lining the bore with impermeable pipes.

It may be worth while here to call attention to the mechanical means adopted by M. Kind in sinking a boring of the large diameter of 8 ft. 4 in., which size was adopted in the well at Passy, to the enormous depth of nearly 2,000 feet from the surface of the ground. The work was commenced with a shaft, as is usually the case, and after it had been sunk to the depth of 50 feet in the original well, the boring commenced, and was continued with, as nearly as possible, the same diameter to the bottom. M. Kind employed for the purpose of cutting through the strata the sliding joint described on p. 62, very closely resembling the joints invented by Œuyenhausen (see p. 55), which allowed the cutting tool to be raised a certain height, and then to be released automatically. This arrangement was adopted in order to avoid the lashing of the sides of the boring by the long rods, and to regulate the force of the blow of the cutting tool. This tool likewise differed from the tools generally

employed, for it consisted of a single or double trepan, according to the nature of the ground, instead of the ordinary chisels and augers. A patent was taken out for the tools in the year 1854, under the number 13,478 of the English patents, the printed specification of which contains a series of engravings of the various modifications of the tools proposed for the different kinds of works ; and in the *Annuaire Scientifique* for 1861 there will be found an illustration of the trepan used by M. Kind and of the slide joints. The patent of 1854 specifies also certain methods of lining the boring ; but it must be confessed that they do not appear to have been successful, for M. Kind encountered greater difficulties from the collapsing of the tubes than from any other cause. It is a common error with well-borers to undervalue the effort exercised by clays swelling when charged with water, and the great delays that arose in the case of the Passy well were precisely attributable to this cause, which partly arose from the false economy attempted to be introduced into the means of tubing the bore. The time actually employed in sinking the well of Passy was very nearly the same as that which had been employed upon the well of Grenelle ; the former took six years and seventy-five days, the latter seven years and ninety days ; but it was the first attempt at sinking to such a depth and in such a strata. The cost of the Grenelle well was £14,000, that of the Passy was £40,000 ; but it must be observed that the quantity of water, delivered at the same height in the two cases, was, as long as the tubes of the well of Passy continued in working order, ten times greater than that at Grenelle. This thing was, at any rate, proved by the temporary results of the experiment of Passy, viz. that the ratio of delivery was in the direct ratio of the diameter of the boring. M. Kind, it may be as well to add, was enabled, by the use of the tools that he employed, to strike as many as twenty blows per minute, at a depth of 2,000 feet, with the greatest regularity.

In a lecture delivered by Mr. Burnell, before 1861, he pointed out that observations should be made upon the yield of the artesian wells of Elbœuf and Rouen, that are fed from the same beds of the lower greensands that are resorted to in the wells of the Grenelle and Passy, in order to be able to ascertain whether the yield of the water-bearing

stratum would be affected. In the state of the well of Passy at that time of course this would have been a matter of little interest, but the necessity of observing closely the effect of two or more such wells upon the probable supply is evident from the results obtained in the neighbourhood of Tours, where the wells were so numerous that they had mutually affected one another. The same thing has also been observed in London, where the artesian wells from the Woolwich sands and the sands of the plastic clay series have ceased to flow over the surface in the great majority of cases; and the level of the water in the chalk is gradually declining in consequence of the great draft that is made upon that source of supply.

CHAPTER VIII.

PROPERTIES OF WATER.

THE essential requirements of a successful well are, first, that water may be procured in sufficient quantity within a convenient distance from the place of consumption, and secondly that the quality of the water shall be sufficiently good for the intended purpose. Unless considerable care is taken in selecting a site, the yield of water may not only be extremely small, but defective in quality, owing to impregnation with saline or other inorganic matter, or even dangerous for human consumption if situated in such a position as to be liable to pollution by organic impurities. In either case the result may be so bad as to render it advisable or imperative to close the well. Hence it becomes necessary that the well-sinker shall have some knowledge of the various qualities and properties of water together with the most suitable methods of purification and the requirements which must be kept in view while seeking a supply of water for a specific purpose.

The uses to which water may be applied can be divided into two principal classes :—

(1) Potable water intended for human consumption and domestic uses.

(2) Water to be used for industrial purposes. In most water supplies in Great Britain no distinction is made between these two classes as in most cases the water authority is able to supply water in sufficient quantity and suitable for all ordinary purposes.

But in cases abroad where good water is scarce, as for instance in France, there is one supply of water which is suitable for such purposes as drinking, cooking, preparing food, etc., and a second supply which may only be used with safety for baths, lavatories, laundry work, flushing or watering roads, gardens, etc.

In addition, water of a special nature may be required for manufacturing purposes such as factory and engine water for use in boilers, or for industrial arts, or finally for agriculture or irrigation.

Potable Water.

With the growth of cities and confinement of large masses of the population in comparatively restricted areas, the supply of water with a high degree of purity becomes of supreme importance and often a problem of considerable magnitude.

Perfectly pure water rarely exists in nature ; it is believed that at some places, notably the water of some springs near Darjeeling on the Eastern Himalayas, absolute purity of water does exist, but generally no water can be found which contains only its constituent parts of hydrogen and oxygen free from any impurities. Even rainwater is not delivered in a perfectly pure state, as it carries with it the impurities, particles of dust, carbon, insects, organisms, fumes, etc., existing in the air ; and further, during collection and delivery into tanks or reservoirs, it acts as flushing water in cleansing the collecting vessel and is contaminated by all the impurities of dust, moss, fungoids, etc., with which it comes in contact. Nominally pure potable water may be manufactured by distillation followed by aeration to make it palatable, but if this process is attempted on a large scale, it is still liable to impurity from contact during these processes.

Fortunately, absolutely pure water is not necessary or desirable for human consumption since the presence of certain salts is both beneficial for the health and makes the water more palatable than distilled water.

It has already been pointed out that the original source of all water supplies is the moisture which is precipitated from the atmosphere. By far the greatest proportion of this moisture is delivered in the form of rain. The presence of dust particles in the air is a necessary preliminary to the formation of moisture-laden clouds so that upon condensation followed by rainfall these dust impurities are carried down and indeed gather further impurities during the fall to the ground. The future history of the water depends upon the course it takes and the ground with which it comes in contact. The water which keeps near the surface will usually become more and more impure until it finally reaches the sea or is evaporated. That part which percolates into the ground and reaches the deep ground-water supplies may purify itself by natural filtration after being perhaps first contaminated

by chemical or organic impurities near the surface or sometimes even at considerable depths, for it is liable to combine with chemicals or organic matter in the strata through which it passes.

Therefore between the time of precipitation and the pumping from a deep well, the water may entirely change its nature owing to a variation in chemical composition, or by the addition of certain ingredients held in solution or suspension. This change will determine whether it is a suitable source of supply either as a potable water or for special industrial purposes.

There is still a popular and natural prejudice in favour of spring water as a source of supply for drinking purposes in preference to any water obtained from surface collection, from open channels, reservoirs, or lakes. It has undergone a process of natural filtration in the geological strata through which it has permeated and at the source is free from the liability to surface contamination from which river water and lake water suffer. As a rule spring-water is bright, sparkling, and well-aerated, all of which are valuable properties of a pure supply, but at the same time the water may contain excessive proportions of mineral matter in solution which render the water unwholesome, if not actually dangerous, as a bulk supply, although possibly valuable in small quantities for special medicinal purposes.

The flow of water along an open channel or storage in a reservoir often enables the original inorganic impurities to be deposited or partly neutralized, while if any organic impurity is introduced in such a course, this may be partly oxidized, assimilated by vegetation or neutralized by the soil of the channel during flow in a certain distance from the place of contamination. Hence this water may be even more wholesome than the spring-water which used to be considered the ideal potable water.

The most desirable qualities of a potable water are freedom from (1) disease organisms, (2) excessive mineral matter in solution, (3) acids.

The water should also be clear, colourless, well-aerated, and pleasant to the taste and smell.

The facility with which typhoid and similar bacteria is transmissible by water is the principal reason for the rigid

exclusion of such organisms from any supply; this matter is dealt with more fully later.

The minerals most commonly found are salts of lime, magnesium and iron, and the principal reasons for their exclusion are that in excessive quantities they cause the water to be hard or unpleasant to the taste.

Hardness is caused by salts of lime or magnesium, and may be either temporary or permanent as bi-carbonates or sulphates respectively are present. Temporary hardness may be removed by boiling or by adding lime. Permanent hardness may be removed by the addition of sodium carbonate. Excessively hard waters are most undesirable for domestic uses and are not generally considered wholesome for human consumption; they affect the flavour of some foods, and are very bad for washing purposes owing to the amount of soap which must be used before a lather is produced. On the other hand it should be noted that very soft waters act upon lead pipes and cases of lead poisoning are on record, the origin of which has been definitely traced to this action. Hardness is measured in degrees (see p. 121).

The water obtained from the chalk deposits is naturally very hard, and as many large supplies in England have their sources in the chalk, softening has become a very important process, and is dealt with more fully on p. 131.

The presence of iron is only objectionable if the proportion exceeds about one part per million, when an undesirable taste and colour become noticeable, and if used for laundry work, rust-spots will appear on the clothes. It is improbable that water containing iron will have any ill-effect on health, and may be beneficial, although it should be definitely determined that the iron salts are naturally present at the source and are not due to any chemical action on the iron pipes

Some waters, as in parts of Derbyshire and Yorkshire, at Leamington, Bath, etc., are beneficial for certain illnesses, but are quite unsuitable for a water supply. Such water in small quantities is a valuable medicine, but may be actually dangerous if supplied in large quantities through iron pipes for domestic purposes.

The acid content of water is usually due to the source of supply being in a peaty district, and every precaution should be taken to ensure adequate purification before such water

is used for a domestic supply. Even a weak acid may have a serious action on metals with which it comes into contact and make the water quite unfit for use as a potable supply. Carbon dioxide in excessive quantities will have a similar action.

Corrosive Action of Water on Iron Pipes.

Certain waters produce excessive corrosion or incrustation of the cast-iron or steel pipes which form the conduit, and on long supply mains it is important that precautions should be taken to ensure that the water does not contain ingredients which will cause this action on the conduit. Incrustation results in an actual reduction in the bore of the pipe which in the course of some years may very seriously restrict the delivery of water. At the same time, the frictional resistance to flow is largely increased, causing a reduced delivery, and the pipe is weakened considerably.

A number of theories have been formulated to explain incrustation and corrosion, but it is now generally believed that it is usually due to electro-chemical action ; in some cases there may be a deposit formed of earthy matter held in suspension in the water, but this is not the typical nodule formation of incrustation.

It has been proved that although the presence of even a weak acid may assist, it is not essential to electrolytic action, but that no electrical action or corrosion takes place when the dissolved oxygen is removed from the water.

Thus it is assumed that a galvanic action takes place between the various particles which compose the pipe, the oxygenated water or weak acid forming the electrolyte. A ferrous salt is formed which is oxidized by the dissolved oxygen to form the more stable hydrated ferric oxide which is deposited on the pipe in the form of nodules.

Steel or wrought iron pipes appear to be more liable to this form of corrosion than cast iron, although the evidence is fragmentary. Cases are on record, however, where a steel pipe has suffered serious corrosion, while an exactly similar cast-iron pipe laid within a few feet and carrying water from the same source has been unaffected. Concrete pipes are now being used considerably for water conduits, and on some important pipe-lines recently laid, cast-iron or steel pipes lined with concrete by the centrifugal process, have been

used. There is not sufficient evidence available to prove definitely that such pipes are entirely unaffected by any potable water which they may be called upon to carry, but it is very probable that they are very much less liable to be affected by corrosion than the ordinary cast-iron or steel pipe.

The most common method of protecting cast-iron pipes from corrosion is to dip the pipes in a hot coal-tar solution known as Dr. Angus Smith's solution. This prolongs the life of the pipe, but it is not an infallible method of preventing corrosion. Secondly the water itself may be treated in such a manner as to neutralize the salts which cause corrosion. The actual chemical used and also the amount will depend on the character of the water, but it has been found that quicklime in the proportion of about 10 ozs. per 1,000 gallons of water treated is a reasonable quantity which will not affect the potableness of the water. If the water is from a peaty soil, some alkali may be added to neutralize the acid properties. If the water naturally contains lime, there is usually little trouble from corrosion. Experiments have also been carried out in de-aerating the water either by boiling or by spraying the water through a vacuum, but although such methods are efficient in reducing corrosive properties of the water, the cost is prohibitive and quite uneconomical in practice.

Water for Industries.

For manufacturing purposes the undesirable properties of water vary according to the industry. It is usually important that the water should be soft, especially if it is to be used in boilers for raising steam. If the water is hard a deposit is formed on the tubes of the boiler, due to the bi-carbonates or sulphates in the water, which quickly reduces efficiency and increases the coal consumption considerably. Scale due to temporary hardness may be removed fairly easily by scraping, but when due to permanent hardness the scale is very difficult to remove. It is also necessary to guard against incrustation in the same way as for potable water. For the cotton industry, brewing, dyeing, etc., certain special qualities are necessary in the water, and it is usually found that the districts where such industries are principally located are limited to parts where sufficient water of suitable quality is available.

Impurities in Water.

After precipitation from the atmosphere, water is either evaporated, or runs off by natural channels, rivers, etc., or percolates more or less deeply into the ground. It is now necessary to examine more closely the impurities which may contaminate that part of the water which is liable to be used for a potable supply.

Surface Water and Shallow Wells.

Many water supplies are obtained directly from rivers or streams, and except under special conditions are not so impure as might be expected. Any surface water is liable to pollution by organic and inorganic impurities, both of which are increased during floods, and vary considerably with the introduction of organic or mineral matter from time to time. Near the source or at any point in a river where the volume of flow is small, the impurities are largely influenced by the character of the bed, but in large rivers the effect is not so great. The chief source of danger of pollution is that due to human habitation near the river, and it is only after considerable precautions have been taken to ensure purity that water which has passed near any densely populated area, may be used for a potable supply, and under no circumstances is it safe to use the water after sewage effluent has been introduced. It has been proved in Great Britain that between an effluent outlet and the mouth of the river at the sea, no river water is sufficiently purified to ensure a satisfactory potable quality.

At the same time, flowing water does tend to purify itself, chiefly owing to dilution, sedimentation, and the effect of sunlight. Some rivers have a very turbid appearance owing to the amount of silt carried in suspension, but this silt is not necessarily harmful, and may act as a precipitant to other impurities. After settlement in a reservoir, such water would be comparatively pure and probably fit for drinking purposes providing the silt did not contain harmful mineral matter.

It is apparent that any stream tends to increase in volume owing to drainage of ground water, as the distance from the source increases, even though there may be no tributaries, and normally this exceeds any increase in impurities (except through densely populated areas) thus increasing the dilution.

As the mouth of a river is approached, the fall usually becomes less and consequently the velocity of flow is reduced, causing the sedimentation of the heavier matter in suspension. This has an important action in carrying down with it the bacteria which is carried along by the water, and which may either be neutralized or destroyed afterwards, but does not constitute an impurity in the water.

Sunlight is destructive to bacterial life, so that its chief effect is to reduce the germ content of the water; but under natural conditions sunlight has not sufficient influence to be regarded as a very powerful purifying agent.

The water in any natural reservoir of sufficient size is usually purer than river water, for the effect of the chief factor in natural purification (i.e. sedimentation) is very much increased. The water is purer at the centre than near to the shores, so that any supply should be drawn as far from the shores as possible.

Water from shallow wells has many of the characteristics of surface water, and is liable to the same pollution, particularly from sewage organisms. It is not so likely to be affected by mineral matter. Great care should be taken at all times to guard the immediate neighbourhood of a shallow well from all possibility of pollution due to sewage, owing to neighbouring cesspools, defective pipes, etc., and to ensure that water is not being drawn which has been exposed to surface contamination of any description. It is advisable, if possible, that the sides of the well should be absolutely water-tight in order to ensure that seepage shall not occur near ground level before the water has passed through several feet of soil. This will assist in eliminating pollution.

Deep Well Water.

The water obtained from deep wells is usually purer than that found at the surface. Certainly cases are known where the water reaches a comparatively deep level after percolation through a very shallow stratum followed by a flow along underground passages. Under such conditions the water may be no purer than a surface supply. But these circumstances are exceptional, and generally the effect of percolation is to reduce the harmful impurities very considerably.

During percolation the forces tending to purify water may

be physical, chemical, or biological. It is apparent that in passing through various strata, the water will be very efficiently filtered, and a large quantity of the solids in suspension will be removed. It is impossible to formulate any rule to show the depth of filtration necessary to remove the solids in suspension, for it will of course depend very largely upon the character of the soil and the nature of the water.

Secondly, some chemical action will probably take place between the ingredients of the water and the strata penetrated. Particularly if the water contains an appreciable proportion of carbon dioxide, many soluble inorganic compounds, such as salts of lime, magnesia, or iron, will yield to its action and render the water hard in character or unsuitable for domestic use.

Finally the biological changes which occur are the most important of the forms of purification, for it is by these agencies that the harmful disease bacteria are reduced. As the water percolates, the organic contents which have been introduced into the water with sewage, etc., are gradually reduced to ammonia compounds, which are in turn converted into nitrites by bacteria in the soil, and finally to nitrates. In this manner, dangerous micro-organisms such as the typhoid and cholera bacteria are reduced, and by the time the water has penetrated several strata, the number of bacteria per c.c. is very small and quite harmless.

Unfortunately it does not always follow that water obtained from a considerable depth, whether pumped or artesian, is bacterially pure. Impurities may find a way in through channels and faults in the strata, and also it is almost impossible to ensure that the pumps or lining tubes which are put in the well are entirely free from bacteria. When once the bacteria has been introduced, the probability is that the quantity will increase rather than decrease, and affect all the water which reaches the well, and in fact will gradually spread outwards, although the development depends to some extent upon the nature of the organic compounds present and whether they are favourable to the growth of bacteria. Continuous pumping, in order to clear out all the water standing in the well, may reduce the number of bacteria per c.c., but it does not always prove to be a successful remedy.

Thus it will be realized that it is most important to make

very careful periodical tests of any potable water obtained from shallow or deep wells, in order to ensure that the requisite degree of purity is being maintained. The importance of obtaining pure water, particularly in densely populated areas, is now fully appreciated, and every effort should be made to maintain a high standard of purity under all conditions. The absence of serious epidemics among the armies in France during the Great War was largely due to the elaborate precautions taken to provide as large a quantity of pure water as was possible in the circumstances. Had the quality been allowed to deteriorate, the water, which is naturally impure and largely surface water, would quickly have been further putrified by the masses of troops concentrated in small areas, and no doubt disease would have spread at an alarming rate.

The demand for copious supplies of pure water has increased enormously during the last 50 years, and at present it is necessary to supply the towns and cities of Europe with 25 to 30 gallons per head per day, while in America the demand may amount to as much as 50 or 60 gallons, although the standard of purity is not so high. The difficulties and expense of providing supplies of such magnitude at once become apparent.

It is even more important that purity should be maintained. There are certain disease-germs—typhoid, cholera, dysentery, anthrax, etc.—which live and move in water, and obtain an entry into the human system by this means. If the bacteria once get into a public water supply, it is almost impossible to prevent a more or less severe epidemic. Such precautions are taken now that an epidemic caused by an impure water supply is practically unknown. Yet it is only in recent years that the importance of bacterially pure water has been completely realized. It was not until the discovery that typhoid was a water-borne disease that the construction of the Panama Canal was possible.

CHAPTER IX.

WATER ANALYSIS AND PURIFICATION.

The Examination of Water.

THE examination of water divides itself naturally into four divisions :—

(1) Physical.
(2) Chemical.
(3) Bacteriological.
(4) Microscopic.

The physical test is the only one which can be conveniently applied by the private investigator, and will only give a partial indication of purity. If an accurate analysis is required, a sample of the water should be sent to a recognized qualified analyst to be tested. Certain precautions should be taken in obtaining the sample.

Separate samples should be taken for chemical and bacteriological tests. At least half a gallon will be required for the chemical test, but less is sufficient for the bacterial test. Glass-stoppered bottles should be used which, for the chemical sample, should be thoroughly cleansed to remove all traces of dust or extraneous matter of any description; the water, of which a sample is to be obtained, should be used for the rinsing. A small space should be left to allow for expansion, and the stopper should not be sealed with wax, but bound up with a piece of cloth.

It is important that a representative sample should be secured, and in obtaining it from a surface supply, the stopper of the bottle should not be removed until the neck is well below the surface of the water. The sample should not be taken from near the bottom of the river or lake, or from any position where the state of the water is likely to be abnormal. No sample should be taken from a surface source immediately after heavy rain.

If the sample is to be obtained from a well, any standing water in the well or bore-hole should be pumped out, and a fresh supply allowed to enter before the sample is taken.

Special arrangements may be made to withdraw the stopper of the bottle when it is at or near the bottom of the well.

In taking a sample from a water pipe, the tap should be turned on and the water allowed to run to waste freely for at least two minutes before the sample is taken.

More precautions must be observed in obtaining a sample for bacteriological examination for it is much more difficult to get a representative one. Simple washing will not cleanse the sample bottle sufficiently, and it is necessary to sterilize it either by baking or steaming for about one hour. Preferably a special vessel should be used, prepared and supplied by a qualified analyst, as this will ensure, as far as possible, that no organism shall be present except those actually contained in the water. The bacteria are liable to change or increase if kept in a bottle for more than one or two hours, so that if an accurate result is desired, and the test cannot be applied immediately, the sample should be packed in ice to retard the change.

The analyst should always be supplied with all possible details regarding the sample, including the exact location of the source, the point at which the sample was collected, the strata in the district, possibility and nature of pollution ; in the case of a well or boring, complete details of construction, depth, water level, whether above or below normal, and any other relevant information, for it is only with a complete knowledge of the history of the water that accurate deductions may be made from the results of the analyses.

Physical Examination.

If water is objectionable to the senses, it is usually sufficient to condemn it as a potable supply, and from that point of view the appearance, odour, and taste are important, and afford some indication of the purity of the supply, but are not reliable under all conditions.

The turbidity of water is perhaps the first quality to be noticed ; muddy or, as it is often termed, dirty water may be objectionable, and some slimes are exceedingly foul, being the breeding ground of a host of aqueous organisms. It would, however, be a great mistake to reject all muddy water as unfit for drinking. Often, sediment will be deposited as soon

as the water is given an opportunity to settle, and clear water may be drawn off.

The process under which suspended matter is precipitated has been mentioned before. The "mud" usually consists of finely divided clay, loam, or sand, and as they are deposited these particles carry down a large proportion of any organic impurity present, and thus cleanse the water. In fact, in case of necessity, it is a safe process to mix some *clean* earth with a doubtful water, thoroughly stir it up, making it as muddy as possible, and then allow it to settle and clarify itself before using. In this process a large proportion of the organisms and animalcules that may have been present in the water, are conveniently localized, and cleared out of the water. Alum also may be used as a clarifying agent.

Turbidity therefore is not a serious objection, unless either the mud itself is foul or semi-putrescent, as in stagnant water such as ponds and marshes left to stagnate for a few months in the year, or disused wells, or unless the mud has been contaminated or contains vegetable or animal matter in course of decomposition.

Clear water should be almost colourless after settlement, with a pure blue tinge when seen in large quantities; for estimating colour a standard may be made by comparing the water with dilute solutions of potassium bichromate and cobalt sulphate or with the aid of the tintometer. In the latter case the colour of the water, as seen looking longitudinally through a tube 2 feet long, is imitated by sliding a graduated glass wedge containing a standard brown solution over a similar wedge containing a blue solution until the same colour is obtained. The thickness of the brown colour required is taken as the degree of coloration due to impurity.

Freedom from smell is an important quality; a putrescent or "fishy" smell may indicate the presence of decomposed organisms or algæ, while tar, peat, or objectionable gases have typical odours. No appreciable smell may be noticed when the water is fresh drawn, so that to test a sample it should be kept in a moderately warm room in a clean bottle not quite full and well corked with a clean cork. If after a few days there is no perceptible odour on uncorking the bottle, it may be regarded as satisfactory.

A pure, soft taste is almost an indispensable accompaniment

to wholesome water, and is due chiefly to the dissolved oxygen and carbon dioxide present. On the other hand, an insipid taste affords no evidence of impurity or unwholesomeness, for pure distilled water and clean rainwater taste flat owing to the absence of the above gases. A bitter taste is generally due to the presence of vegetable organic carbon or to organic impurity from a vegetable source—such as decayed leaves, rotten wood, dead marsh plants, etc.

The senses of smell and taste are not highly developed in the majority of people, and although a *difference* may be discernible between certain samples of water, the average person is unable to describe it accurately, so that too much reliance should not be placed in these tests.

Chemical Tests.

The object of a chemical test is to determine so far as may be necessary, the chemical compounds present in the water, and then to deduce from the data obtained, whether the water is suitable chemically for human consumption. Water which has, apparently, a bad chemical composition is not necessarily dangerous, but must be regarded so, in the absence of evidence to the contrary if certain proportions are exceeded.

Water which has been contaminated at any time by sewage is regarded as unwholesome, so that if certain chlorine or nitrogen compounds, which are typical of sewage, are present in excessive quantities the water must be regarded as unwholesome, owing to the possibility of disease germs being present. Yet the chlorine or nitrogen compounds may be due to saline or mineral matter and no indication of pollution. Again, traces of sewage pollution cannot always be conclusively detected by the presence of these compounds, so that a chemical analysis cannot be regarded as conclusive without the aid of a bacterial examination and an intimate knowledge of the source of supply together with all the relevant information appertaining to it.

The principal tests to be applied in the analysis of water are given below, but these are merely intended as a guide to the meaning of an average analysis Only an expert should attempt the final interpretation of a water analysis, as results are liable to be very misleading if full regard is not given to the many varying factors, not only in the chemical, but in all

the examinations. In certain cases it may be necessary to apply further tests in addition to those given here, but these are exceptional and would be superfluous in this short description. No attempt is made to give the methods of carrying out the tests since this is purely the work of a chemist, and could not conveniently be given here.

1. *Residue left after Evaporation.*

The residue will naturally vary considerably in character depending upon the history of the water. An experienced observer can estimate the nature of the deposit with considerable accuracy from inspection. For instance, the residue should be quite white and small in quantity. Charring usually indicates the presence of organic matter, especially if accompanied by a disagreeable smell. The total residue will vary with the source of supply; for instance, while water from an upland source should leave only a small residue of 4 to 6 parts per 100,000, water from chalk strata may give 150 parts per 100,000, and in exceptional cases, considerably more.

2. *Nitrites.*

A test for nitrites should always be made; even a trace, although not entirely conclusive, should be regarded as a suspicious sign since nitrites are always present in incompletely purified sewage in which the nitrogenous organic matter of animal origin is in course of decomposition. If an excess of free ammonia is also present it is a further indication of pollution, although it should be remembered that nitrites may be produced from other sources besides sewage with the formation of ammonia. In deep well waters nitrites may be present without danger, especially if traces of metals, lead, iron, or zinc, are found.

3. *Nitrates.*

The presence of nitrates in water usually indicates previous pollution, and if there is much unabsorbed oxygen present it is probable that the pollution is recent, although no limits can be regarded as safe without a knowledge of the source of supply and the nature of the strata.

The nitric nitrogen or amount of nitrogen present in nitrates is the real measure of pollution; the action (which may be

due to bacteria or may be entirely chemical) is probably as follows: the animal organic matter in course of decomposition and percolating through the soil, produces nitrogen which is turned into nitric acid and reacting with carbonates in the soil gives nitrates. The nitrate itself is harmless, and, if from a knowledge of the district and the source of supply it is known that the pollution is remote, it may be ignored subject to the results of other tests.

4. *Chlorides.*

Chlorine in itself is quite innocuous in small proportions, and in fact is now largely used as a purifying agent (see p. 129). Yet its presence as chlorides in excessive quantities may indicate pollution, since it is an inevitable accompaniment of sewage, particularly if the presence of organic matter is indicated by the charring of the residue after evaporation and the amount of oxygen consumed. Chlorides are always present in the water, and a normal proportion may be taken at about 4 parts per 100,000. At the same time chlorine is capable of considerable penetration, and may be present in large quantities after all pollution has disappeared. Also, of course, the chlorine content will increase considerably in cases of contamination by salt water.

5. *Hardness.*

In an ordinary analysis only the nitrates and chlorides are estimated, and if the determination of total hardness indicating the calcium and magnesium compounds present accounts for the whole of the solids no further examination is necessary.

The hardness is the soap destroying power of the water, and is measured in degrees. Thus one degree represents the amount of soap destroyed by one part of calcium carbonate (see also p. 131).

It may be permanent or temporary, and is an indication of the sulphates and carbonates, of calcium and magnesium present in the water.

6. *Metals.*

A test should be made for the presence of lead, zinc, iron, or copper. The presence of the metal is usually due to the action of the water on pipes, tanks, cisterns, etc., although in

the case of iron it may be naturally present in the water. Lead particularly must be excluded and even the slightest trace regarded as a danger to the supply. Traces of other metals are not important, although iron should not be present in water used for laundry purposes, owing to its staining action.

7. *Organic Matter.* (i) *Free and Albuminoid Ammonia.*

The amount of ammonia present is usually some indication of the organic matter present, although it must be remembered that water passing through long lengths of iron pipes, ferruginous sands or peat may contain a considerable proportion of ammonia due to the reduction of nitrates.

The ammonia present is usually estimated as "free" and "albuminoid" ammonia. Ammonium salts are nearly always present, and when the water is distilled the ammonia given off is spoken of as "free". If, now, a strong alkaline solution of Potassium Permanganate is added, and the distillation is continued, a further quantity of ammonia may be given off, which is referred to as "albuminoid". The albuminoid ammonia does not exist in the water itself, but is produced by the action of the alkaline permanganate in decomposing the nitrogenous organic matter and therefore represents pollution.

If the free ammonia amounts to more than ·01 parts per 100,000 or if there is a high ratio between free and albuminoid ammonia the pollution is probably due to sewage.

If there is no trace of metal in the water and it is not obtained from a deep well source where a large proportion in the water is natural, the presence of ammonia usually indicates serious pollution.

(ii) *Oxygen Absorbed.*

The amount of oxygen which a water is capable of absorbing is an indication of the organic content. The test is usually carried out by finding the amount of oxygen absorbed from an acid solution of Potassium Permanganate when kept at 80° F. for four hours. Some analysts stop the action at three hours, while others boil the solution for fifteen minutes. This results in a considerable disparity in results, and to avoid this, the method of carrying out the test should always be stated. Normally a water should not absorb more than ·10 part per

100,000 in four hours, at a temperature of 80° F., unless the source is in a peaty strata, when the proportion may be increased considerably.

Any test for organic matter should be considered in conjunction with the bacteriological tests.

Bacteriological Examination.

The bacteriological examination is perhaps the most important of all tests applied in the analysis of water, since it indicates exactly the nature of the most dangerous of all pollution, and also the actual bacteria present. The tests need very careful interpretation, together with a knowledge of the source of supply, and should only be attempted by a bacteriologist accustomed to the analysis of water. Divergent results have been obtained by different analysts in the past, owing to the lack of uniformity in methods of working, so that it is important to know the culture media used, the temperature and period of incubation for the interpretation of results. The principle of the examination is the application of qualitative and quantitative analyses to determine respectively the character and number of bacteria capable of growing in certain nutrient media. The number of organisms which can be detected expresses the degree of purity of the water. Thus the smaller the amount of water in which the organisms can be detected the greater is the pollution. The result of a test is expressed as the number of bacteria per cubic centimetre.

It is impossible to give here the complete details of a bacteriological examination, but the general principle of procedure may be indicated.

A sample of the water is taken and a colony of the bacteria is cultivated on specially prepared nutrient media such as gelatine or agar, which are most generally used. Cultivation on gelatine is at a temperature of 20°–22° C., and the bacteria are counted on the third day. If agar is used as culture media the temperature should be 37° C., and the bacteria counted after 24 hours. The preparation of the nutrient media should only be carried out by a qualified bacteriologist, and the test should always state whether the bacteria were counted with or without the aid of a lens or microscope.

Such tests as the above may be termed definite quantitative tests indicating exactly the extent of bacteriological impurity.

In addition to these, certain presumptive tests may be applied which determine the nature but not the extent of the pollution and although not conclusive are sufficient to indicate the origin and condition of the bacteria present.

Presumptive tests consist of observation of the action of the bacteria in the water upon certain sugar solutions such as dextrose or upon bile-salt lactose broth. If there is fermentation with the production of acid and gas, it may be taken that sewage bacteria are present. A presumptive test which is negative indicates, but does not necessarily prove, the absence of sewage pollution.

The more important bacilli searched for are those of the typical sewage type, and particularly intestinal bacteria, which definitely indicate pollution, such as *bacillus coli communis*, *bacillus enteritidis sporogenes*, and *streptococci*. The *B. coli* is most important, and if the tests for this group are favourable the other tests may usually be relaxed; in special cases tests must, of course, be applied for other types.

With the exception of the indications of pollution afforded by presumptive tests and referred to above, it is inadvisable and misleading to give here definite standards regarding the number of bacteria allowable. This depends upon a variety of circumstances and for further information which will assist in the decision as to which samples to regard as bacterially pure, the reader is referred to a reliable work on this subject such as *The Examination of Water and Water Supplies*, by J. C. Thresh.

The bacteriological examination is not only one of the most conclusive tests for the detection of dangerous pollution, but in addition it shows, very definitely, the efficiency of any system of filtration or other method of purification, and also the effect of rainfall and floods upon the purity of well or river water. Although it is only during recent years that the importance of bacteriology has been appreciated, it is now regarded as one of the surest tests at our disposal, and more reliance is being placed upon it every year.

Microscopical.

The microscopical examination is chiefly of value in corroborating the results of other examinations. The inorganic particles found will indicate some of the mineral properties

and the presence of organic particles will indicate possible pollution. Some living organisms may be found, such as parasites or eggs of parasites, which are undesirable. Also animal or vegetable organisms may be detected which, while not actually dangerous, affect the colour, odour or taste enough to make the water unfit for consumption. With a knowledge of the nature of the matter causing the trouble, steps may be taken to eliminate it and render the water fit for drinking.

It is important that the results of all analyses should be carefully tabulated and considered in relation to each other. It is quite impossible to lay down definite standards of purity, for all such limitations are misleading. It is particularly important that the source of supply should be carefully examined and the possibility and nature of pollution stated in the analysis.

The records of analyses are of great assistance in determining the suitability of a new water supply as a potable water, and also in solving problems of flow of underground water.

Methods of Purification.

It is only in isolated instances that natural water can be supplied directly from the source to the consumer without previous treatment, and such cases are always small supplies, obtained locally in a sparsely populated area.

The water obtained from deep wells is more reliable than the majority of surface waters for reasons already indicated, and may be supplied directly from the source without danger. But such water is often too hard, or contains too much mineral matter of some description for ordinary domestic or industrial uses, so that treatment becomes necessary.

The properties required in water for domestic and industrial uses respectively have already been indicated (p. 107), and it is only necessary to mention here that a moderately soft water is practically always desirable, and that low content of pathogenic organisms is essential in potable water, or water used in brewing, sugar manufacture, starch manufacture, and allied industries, particularly where fermentation is an integral part of the process. Water containing iron is particularly undesirable in paper-making and dyeing industries.

The modern methods of purification are merely outlined below. Water purification is an extensive study in itself, and a reliable modern work on the subject should be consulted for detailed information.

Sedimentation is the simplest and natural form of purification, and in waters where the impurities are mostly inorganic a good potable supply may be obtained with this treatment alone. A certain amount of organic matter is also carried down during the settlement in the manner already explained, but no reliance may be placed on this for eliminating dangerous bacteria.

The purification increases as the period of settling increases, but a limit is usually placed upon this by the economic size of the storage reservoirs. Generally, at least 24 hours sedimentation should be allowed, and in some cases more than a month is provided for. Other factors usually have to be considered in estimating storage; for instance, to provide against drought and to avoid supplying the reservoir with surface waters immediately after storms, when the matter in suspension is considerably increased.

Precipitants are sometimes added to assist in sedimentation and in clarifying the water. Sulphate of alumina is commonly used, and when added, usually in the proportion of one or two grains per gallon, to water containing carbonates of lime and magnesia, carbonic acid is set free, and calcium and magnesium sulphates are formed, together with hydrate of alumina, which is a gelatinous material and constitutes the precipitant. The action is expressed by the equation :—

$$Al_2(SO_4)_3+3CaCO_3+3H_2O=Al_2(OH)_6+3CaSO_4+3CO_2.$$

It will be noticed that calcium sulphate is formed; this will of course tend to increase the permanent hardness, but the increase is usually unimportant. It is essential that sufficient lime should be present in the natural water to complete the above action, and in some cases it may be necessary to add lime. It is also important that the precipitant should be introduced in correct proportions, varying with the quality and quantity of water treated. Various devices are available to ensure that uniformity shall be maintained. Precipitation is sometimes necessary as a preliminary treatment to rapid filtration (see p. 128).

Slow Sound Filtration.

While sedimentation will effectually remove suspended matter and clarify the water, it is ineffective for removing the micro-organisms which constitute the chief danger in potable supplies.

In the past the most extensively used method of purification has been filtration through layers of sand contained in a large filter bed, and this method has been proved to be very satisfactory in reducing the bacterial content to safe limits.

The sand filter was originally designed to remove suspended matter, and its complete action was not appreciated for some time after the method had been proved to be most effective. The purely mechanical filtering action in the process is relatively unimportant, and the efficiency of the filter really depends upon the formation of a jelly-like deposit in and on the surface of the filter. This is an organic growth which appears on the surface some time after the water is turned on to the filter, and which acts as a barrier to the bacteria in the water and also assists in the nitrification of organic matter. The minute cells and organisms which form this deposit are some days in appearing, and the action of the filter is only satisfactory when the growth is complete.

It will be quite apparent that one effect of this film will be to cause clogging in the filter; and in practice it is found that the superficial filtering material must be removed and thoroughly washed, or else replaced at least once or twice per month. This necessitates putting the filter out of action for some time, not only for the washing but also until the film has again formed, unless a film is artificially formed by the use of a coagulent. Alum or minute doses of copper sulphate added to the reservoirs prior to filtration is sometimes effective in increasing the length of run of the filter. But in any case the suspension of operations is a great disadvantage to the slow filter, for additional capital outlay is necessary for the construction of duplicate beds.

The sand, which acts primarily as a support for the organic deposit, and secondarily as a mechanical filter, is from 2 to 3 feet deep and rests on a foundation of about 12 or 18 inches of gravel graded to suitable sizes. The water level is usually about 2 feet above the surface of the sand, and underdrains in the floor of the filter carry the effluent to a collecting channel.

Owing to the cost of maintenance of the sand filter, which is high, and to the fact that it cannot be relied upon always to give uniform treatment, it is rapidly falling into disuse in favour of the modern rapid filter, or alternative methods of treatment, which are nearly always adopted in new purification schemes.

Rapid Filtration.

The principle of the rapid filter is the same as that of the slow filter, but the unit is smaller, works at a higher speed under pressure, and is more constant and reliable in action.

The apparatus is quite self-contained, and consists, in the smaller units, of a vertical mild steel cylinder, about 8 feet diameter and 7 or 8 feet high, containing the filtering material and suitably designed to withstand the working pressure, which may be anything from 3 or 4 lb. per sq. in. to 150 lb. per sq. in. or more. The filtering material usually consists of crushed silica or quartz, about 3 or 4 feet thick, resting on a foundation of larger material. If necessary, a layer of polarite may be introduced for the removal of iron from the water. The capacity of a filter of this type would be between 100 and 130 gallons per sq. ft. of filter per hour, dependent on the pressure, etc. By means of special gear a trace of coagulent (sulphate of alumina, see p. 126) may be added, if required, in exact ratio to the volume of water passing through the filter.

The water is admitted at the top of the cylinder, and is sometimes aerated by compressed air before reaching the filtering material.

The filter may be cleaned either by mechanical agitators or stirrers, or by driving compressed air upwards through the sand to loosen it and dislodge foreign matter. The latter method is preferable. The flow of water is then reversed, and passing upwards carries the deposit with it to the waste-water pipe. Washing only occupies about 12 or 15 minutes every two or three days, depending upon the character of the water under treatment; the amount of water wasted is a negligible percentage of that treated. The filter is ready for effective operation almost immediately after washing, and may be depended upon to maintain a uniform degree of purification. Larger units have horizontal cylinders for

convenience of construction. But for the treatment of large supplies a battery of filters of the smaller type should be erected with a suitable total capacity for the volume of the flow. The latter method is preferable and more usually adopted, as it provides a flexibility in the treatment. Various types of filters constructed on these principles are now available, suitable for the purification of almost any character of water and for any volume of flow. Generally, the advantages of the rapid pressure filter over the slow filter are (*a*) reduced cost of installation and working, (*b*) reduced area of land required, (*c*) greater degree of purification and more uniform results, (*d*) simplicity and flexibility of control, (*e*) the filters may be situated on the rising main of a pumped supply between the pumps and the service reservoir, without appreciable resistance.

The Addition of Chemicals.

Chlorination.—In many supplies purification is now effected by the addition of chlorine. If small quantities of bleaching powder (calcium hypochlorite) are added to the water the active chlorine will effectively destroy all harmful bacteria. Recently, liquid chlorine has been used very successfully, and is more convenient in practice than the bleaching powder treatment, owing to the difficulty of estimating the correct quantity of chlorine in the latter case. In addition, calcium hypochlorite is liable to produce a deposit which does not appear when liquid chlorine is used.

Chlorine is liable to produce an unpleasant smell and taste in the water if added in excessive doses, and in exceptional cases it may be necessary to dechlorinate the water.

The chlorine should be introduced into the reservoir at least 100 feet from any valves or other metal liable to be attacked by it. When completely assimilated by the water it has no effect on metals, but if the solution is too strong corrosion will take place.

Other chemicals are sometimes used for purification, but only to a smaller extent. The principal sterilizers are alum, ozone, copper sulphate, and hydrogen peroxide, all of which are powerful germicides. The two latter may only be used in minute quantities or they will render the water unsuitable for human consumption, but in the quantities usually necessary

to destroy the bacteria (copper sulphate about one part in 8,000,000 and hydrogen peroxide about one part in 100,000) are quite harmless.

Although chemical treatment prior to filtration is not usually recommended, except for purposes of precipitation, small quantities of copper sulphate may sometimes be added with advantage to reduce the numbers of certain organisms which may occasionally so clog the filters as to make them very inefficient, if not useless.

Aeration.

Although aeration will not effectively reduce the number of bacteria in water it has a valuable purifying action in removing offensive tastes or smells due to dissolved gases from previous putrifaction.

Aeration is usually found to be an essential feature of the treatment of water in tropical countries, where the growth of algæ is very rapid and where odours very easily develop as a result of fermentation or putrifaction. The aeration is usually effected by allowing the water to overflow from a bellmouth and pass downwards over a series of weirs in the form of a cascade. Jets may also be used to spray the water into the air in the form of a fountain.

Purification by Electricity.

Electricity may be used for purification in two principal ways: first by electrolytic action and secondly by electric ray treatment.

The electrolytic purification may be due to the production either of a disinfectant or a precipitant

By the electrolysis of salt-water, sodium hypochlorite is produced. This is a powerful disinfectant, and has a similar sterilizing effect to chlorine.

Secondly, ferric hydrate may be produced by electrolysis, and acts in a similar manner to alumina hydrate in precipitating impurities (see p. 126) The expense of this method is greater than for the production of the hydrate in the usual way, by adding the sulphate of alumina of iron, but an advantage is gained by the fact that no objectionable matter is produced in the water and the hardness is not increased.

Electrolysis is also usually the method employed for the production of ozone when it is used as a purifying agent.

Ozone purification is very effective in removing bacteria, but is expensive and necessitates a very high voltage current. The process is in use at a number of places abroad, particularly in Germany, and is relied upon to purify very badly polluted river waters. The Siemen's ozonizer is the apparatus usually employed.

Electrical energy may also be used for purification in the form of "violet rays", which are found to be most effective in sterilizing water. This method has never been found economically practicable on a large scale.

Water Softening.

It has already been shown that salts of lime and magnesia make water hard and that carbonates cause temporary hardness, removable by boiling, while sulphates cause permanent hardness, which may only be removed by chemical reaction.

Hardness is usually expressed in degrees on Clark's Scale, in which 1 grain of calcium carbonate present in 1 gallon (70,000 grains) of water is equivalent to 1 degree; or hardness = the number of grains of calcium carbonate per gallon. On this scale, more than 15° is termed a hard water; between 5° and 15° is moderate; and less than 5° is a soft water. The total hardness may be both temporary and permanent if carbonates and sulphates are present.

It is obvious that the whole object of water softening is to get rid of the carbonates or sulphates; the usual method of doing this is by simple chemical precipitation.

Temporary hardness: Carbonates of lime and magnesia are held in solution by carbonic acid and so converted into soluble bicarbonates. If the water is boiled, the carbonic acid is driven off and the insoluble calcium carbonate is precipitated thus:—

$$CaH_2(CO_3)_2 = CaCO_3 + CO_2 + H_2O,$$

and the resulting water is softened.

Small quantities of water for household purposes may be softened in this way, but it is not the most convenient method upon a commercial scale.

There are, however, systems in use for the supply of soft boiler feed water in generating stations, for instance, where the exhaust steam is brought into contact with the hard water and heats it sufficiently to precipitate the carbonates and so produce a water sufficiently soft to avoid scale on the boiler tubes. Considerable economy may thus be effected of course.

The most common method of water-softening is that known as Clark's Process, which consists in adding lime water in sufficient proportions to cause the precipitation of the carbonates, thus producing the same result as boiling.

The action may be expressed as follows :—

$$CaH_2(CO_3)_2 + Ca(OH_2) = 2CaCO_3 + 2H_2O.$$

or if magnesium bicarbonate is present :—

$$MgH_2(CO_3)_2 + Ca(OH)_2 = MgCO_3 + CaCO_3 + 2H_2O,$$

But magnesium carbonate is quite soluble so that an additional amount of lime must be added to carry the action further and so form the insoluble magnesium hydrate thus :—

$$MgCO_3 + Ca(OH)_2 = Mg(OH)_2 + CaCO_3.$$

The hydrate and carbonate is precipitated.

Although there are variations in working the process, the general principle is the same in all. Chalk lime ($CaCO_3$) must be used, and should be thoroughly burnt to drive off the CO_2 and so be reduced to caustic lime (CaO). This caustic lime is then slaked in special chambers by adding soft water, thus forming a cream of lime which is introduced into lime water tanks where the cream of lime is agitated in contact with water, and lime water $Ca(OH)_2$ is formed ready for treating the hard water. The quantity of lime in the lime water must be equal to that already contained in the bicarbonate. After the lime-water treatment, the water may either flow into settling tanks, where the solids are deposited and the clear softened water allowed to pass to storage tanks, or may be carried through some form of rapid filter to remove the solids. It is interesting to note that the addition of lime has the effect of reducing the number of harmful bacteria in the water.

Permanent Hardness.—After boiling or precipitation as indicated above, residual hardness may yet remain owing to the presence of sulphates. These may be removed by adding

sodium carbonate, when the calcium sulphate is converted into insoluble calcium carbonate and a harmless sodium sulphate is left in solution thus :—

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

The reaction is exactly similar for magnesium sulphate, magnesium carbonate being formed which must be converted into the hydrate by lime as before.

Chlorides or nitrates may be removed in the same way as sulphates. It is important that the correct quantity of lime or soda respectively should be added both for the sake of economy and to ensure the complete chemical reaction.

Self-contained units are now made by a number of manufacturers, in which every precaution is taken to ensure that each gallon of water shall receive its correct dose so that a uniform quality of water is obtained. Special arrangements are also provided for removing deposits and for extracting all light solids which will not settle.

The Base-exchange System of Water Softening.

The class of mineral substances known as zeolites possess the important chemical property of being able to exchange their bases repeatedly with other chemical bases. The natural mineral zeolites consist of silicates of sodium, alumina, calcium and potash, together with water, and can be used for softening water by reason of the exchange of the sodium in the zeolite with the calcium in the water.

Thus in the case of temporary hardness, when the water is allowed to percolate through a bed of zeolite under suitable conditions, the sodium is replaced by calcium from the calcium bicarbonate in the water and sodium bicarbonate remains in the water. Any magnesium is also replaced in a similar manner. Also in the case of permanent hardness the sodium in the zeolite is released and replaced by calcium from calcium sulphate in the water while the sodium enters into combination to form sodium sulphate in the water. In each case the substance remaining in the water is soluble so that no deposit is formed and there is no harmful effect upon the character of the water.

In course of time the whole of the exchangeable sodium in the zeolite will be replaced by calcium and its softening

properties are then exhausted. However, it is found that by merely allowing a 10 per cent. solution of common salt to percolate through the bed of zeolite the softening properties are regenerated and the process may be continued. In this case the calcium taken up by the zeolite exchanges with the sodium in the salt and the zeolite regains its original sodium content.

It is now a well-known fact, however, that artificial zeolites can be manufactured economically and can be depended upon to give much better results than the natural mineral. These are sold under various patent names, and can be found in the advertisement columns of any technical paper dealing with water supply. The apparatus for carrying out the action usually consists merely of a cylindrical metal container to hold the material, with supply, delivery, and waste pipes to allow the water to percolate freely, either by gravity, or under pressure, through the softening media. If a continuous supply of soft water is required, it is usually necessary to provide either duplicate apparatus or else to provide sufficient storage to allow for the time required for regeneration of the media, although this is only a small proportion of the total working time.

The simplicity of the base-exchange system is one of its principal advantages, but, in addition, a perfectly soft water may be obtained, no deposit is produced, very little attention is required by the plant and the only important cost of maintenance is the supply of a salt solution for regeneration.

As in the other softening processes, preliminary clarification by the use of a coagulent, such as aluminium sulphate, may be necessary if the water is discoloured or contains minute organisms.

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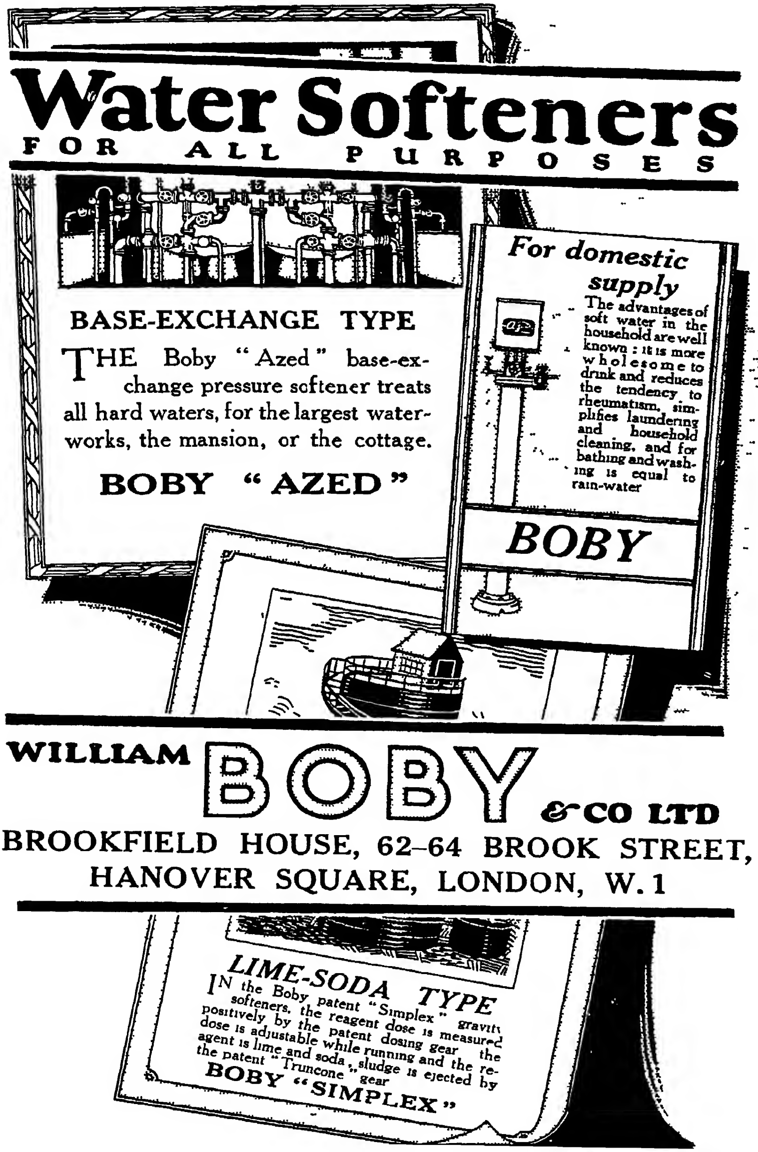
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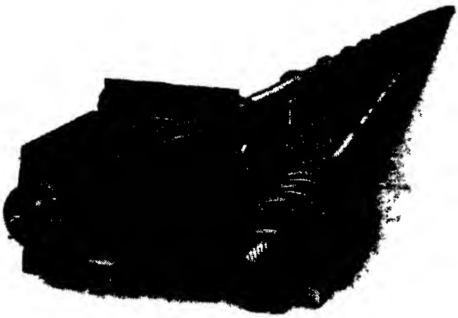

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